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LIGHTWAVE MODULATION AND SIGNAL PROCESSING IN FREE-SPACE OPTICAL COMMUNICATION: A STATE-OF-THE-ART REVIEW

Sandeep Rajendra Jadhav

Electronics and telecommunication, Pune Vidyarthi Girha's College of Engineering and Technology and G.K.

Abstract: FSOC enables the transfer of data using optical carriers such as visible, infrared (IR), and ultraviolet (UV) light, without the need for physical medium. FSOC is commonly employed in Free-Space Optics (FSOC) to facilitate rapid data transmission between fixed locations over long distances. The wide optical bandwidth enables it to achieve higher data speeds compared to standard RF links. FSOC operates in the unlicensed spectrum above 300 GHz, which sets it apart from RF technology. This enables simple installation and robust security without being subject to regulatory limitations. The FSOC can be deployed where installing of fiber optics cable might be tough and may get costly. FSOC communications allow long-distance data transmission for scientific research projects and make satellite connections easier. Modulation is necessary to transmit baseband signals in communication networks. This enhances the effectiveness of the channel and reduces the occurrence of interference. OOK, PPM, BPSK, POLSK, OAM, OFDM, CSK and QAM are employed in FSOC. This system is explained below in this paper. These techniques enhance and optimize optical wireless communications.

Keywords: Free-Space Optics Communication (FSOC), line-of-sight (LOS).

INTRODUTION

In FSOC transfer the signals in unguided propagation media using optical carriers, such as visible, infrared (IR), and ultraviolet (UV) bands. FSOC systems are employed for transmitting data at high rates between two stationary locations over distances that can span several kilometres [1]. FSOC technology differs from communication over optical fiber in terms of the channel medium. Light-based wireless communication networks, also known as FSOC or fiberless optical communication networks, use light as a carrier and air as an unguided propagation medium for transmission [2]. FSOC lines possess a significantly large optical bandwidth, enabling the transmission of data at much higher rates. Currently, the term "wireless" is commonly used interchangeably with radio-frequency (RF) technologies due to the widespread use and implementation of wireless RF devices and systems [1]. FSOC system works on the line of sight (LOS) [3]. The number of repeaters reduced because of FSOC [4]. FSOC has distinct advantages over optical fiber connection, including its simple installation process that does not need dealing with right of way issues or disrupting existing infrastructure. Therefore, FSOC has garnered renewed attention in recent decades. FSOC technology enables high bandwidth transmission without the need to purchase licensed frequency bands [5-6]. This is because FSOC communication utilizes frequencies over 300 GHz, which fall under the unlicensed spectrum. It is also interference-free [7-10]. Compared to radiofrequency communication, FSOC (Free Space Optical) communication is more difficult for unwanted parties to intercept because the optical signal precisely focused into a small beam. Since the intended recipient is the only one receiving this beam, intercepting it by others will be more difficult [11]. The EMI immunity of the FSOC signal is more than RF [12]. Since laser communication is a great option for last-mile connectivity, it can be employed in metropolitan area networks to offer LAN connectivity and intercampus links [13].

Free-Space Optics (FSOC) technology uses high-speed wireless connections, both on the ground and in space [14]. When the optical wave of the FSOC system propagating through inhomogeneous medium the atmospheric effect strongly affects the signal [15]. FSOC technology is proven to be a great asset in the field of space communications. Intersatellite links are currently being investigated as a means to facilitate smooth data transfer between satellites in orbit. Furthermore, FSOC exhibits potential in long-range communications in outer space, since its exceptional data transfer capabilities enable the transmission of substantial amounts of data across extensive distances. This capability is crucial for scientific expeditions and missions involving remote sensing. FSOC technology is being used more and more for enterprise connectivity and as a backup link solution on land. FSOC offers enterprises and organizations a fast and dependable method for creating strong communication networks. It is especially beneficial in situations where conventional cable connections may be problematic or too expensive to establish. Furthermore, FSOC systems function as efficient backup connections, guaranteeing uninterrupted service in case of network failures or disruptions in primary communication networks. The value of optical communications through the environment goes beyond commercial uses; it also has significant relevance for defence applications. FSOC technology provides secure and high-bandwidth communication channels in military and defence settings, which are more resistant to interception and jamming than traditional radio frequency systems. This skill is crucial for preserving secure channels of communication and executing intricate procedures. Due to its versatility and high-performance properties, it is a vital instrument for meeting the increasing demands of modern communications infrastructures [16]

Low-cost infrared emitters and detectors with high-speed capabilities are readily accessible. The infrared spectral region provides an almost boundless range of frequencies that is not subject to any international regulations. Infrared and visible light have different wavelengths and display similar qualitative characteristics like Both are absorbed by dark things, diffusely reflected by light-coloured objects, and secularly reflected from glossy surfaces. Both forms of light can pass through glass, but they are unable to pass through walls [17]. Unlike fiber optic communication, which transmits the message or data within a guided light-carrying fiber, FSOC communication technology uses modulated visible or infrared (IR) lights, produced by either light-emitting diodes (LEDs) or lasers, through a random atmospheric turbulence channel to establish communication between two points [18].

The FSOC is travels from the atmosphere so the impact of weather condition is more on this optical signal [19]. Ambient light noise, interference, and multipath dispersion can lead to inter symbol interference (ISI) [20]. The ratio of the initial light intensity (scene irradiance) to the attenuated scene intensity (irradiance) is known as the scattering coefficient [21]. There will be power loss due to the beam alignment also [22]. The beam motion is also one of the main causes for major power loss [23]. The intensity noise caused by atmospheric parameter changes, or so-called capacity limiting variables, is what restricts FSOC. These factors are dependent on the local meteorological circumstances that deflect and/or scatter the laser beam as it propagates. The ratio of the initial light intensity (scene irradiance) to the attenuated scene intensity (irradiance) is known as the scattering coefficient

[24]. Typically, the FSOC wavelength is chosen to align with atmospheric absorption windows to minimize signal loss. The principal cause of irradiance attenuation is the Mie scattering resulting from fog, haze, and aerosol. Due to the complex shapes and orientations of the particles, it is not feasible to calculate the value of the attenuation coefficient in advance. The experimental results have shown that dense fog can provide an extinction coefficient of up to 270 dB per kilometer [25]. Remarkably, the reduction in irradiance caused by dense fog, snow, and haze is discovered to be unaffected by the wavelength of light [26-27]. FSOC systems utilize the optical sources and photodetectors already employed in optical fiber transmission. In order to fulfil the high availability demands of the telecoms industry (with a need of over 99.9% availability), during periods of dense fog, The maximum range of the FSOC is around 500 meters [28]. The transmitted beam vibrates as a result of the building wobble, moving it away from the receiver's line of sight (LOS). The bit error rate (BER) rises as a result of these vibrations, drastically impairing the performance of the link and lowering the average received signal. The primary causes of the loss include scintillation, wavefront aberration, scattering, atmospheric absorption, and beam wandering [8],[3]. Scintillation refers to the atmospheric turbulence that has a significant impact on laser beams used for transmitting information in outer space. Turbulence exhibits unexpected behaviour and leads to random variations in the optical irradiance received. This can cause severe distortion in the received wavefront and greatly reduce the sensitivity and efficiency of the receiver, resulting in a major decline in the performance of the FSOC system. Various methods have been used to mitigate the impact of turbulence and address this problem. These methods include reducing the size of the receiving opening, employing an adaptive optics system to correct wavefront distortions, utilizing multiple input multiple output (MIMO) technology, and considering an efficient modulation scheme [29-30]. Furthermore, on a horizontal and an uplink path, the turbulence variations cause the laser beam at the detector plane to fluctuate both spatially (wavefront aberration) and temporally (beam wandering). Beam wandering generally causes an increase in the irradiance fluctuations called effective scintillation, or beam-wander-induced scintillation, whose ensemble average is referred to as ESI. In the event that the beam is concentrated or collimated, beam-wander effects must be considered [31]. Photons are said to be extinguished along their propagation path during attenuation. When a laser beam is attenuated, the excitation is shifted instead of the photons being extinguished. Furthermore, air turbulence causes phase-front distortions that cause the incident beam to deflect (optical propagation), commonly known as focal-spot wandering (FSW). At the receiver aperture, all of these factors lead to both instantaneous received power variation, or fading, and average received power loss. Eventually, this results in a higher bit-error-rate (BER) and a lower channel capacity and system reliability as a whole. These impacts halt FSOC's high data rate. link from reaching the five nines, or 99.999%, availability. Increasing the optical power level that is launched into the air when the propagation loss reaches a certain point is one way to solve these issues. On the other hand, the cost will rise dramatically if high-power optical amplifiers are used as boosters. Using a slightly divergent beam and receiving it with a bigger aperture telescope is an additional method for minimizing optical power fading. Nevertheless, a diverging beam typically results in a considerable loss of average received power, and expanding the telescope's aperture will also cause background radiations to be collected. Therefore, FSOC performance loss or degradation may not be balanced by the advantages of increasing the optical power and/or employing slightly divergent beam with bigger receiver aperture (greater than or close to the long-term laser spot size) [32]. So, there is one more effect of atmosphere by power loss takes place it is beam wandering and it can be solved by using the opto electronic assembly we can improve performance of FSOC system [33].

Developing a proficient control system for beam auto-aligning, tracking, and positioning (ATP) is essential for reducing beam wandering and greatly improving beam stability on the receiver plane. Adaptive control of the beam direction to stable the beam image at a specified point is known as laser beam Aligning, Tracking, and Positioning (ATP), and it is a crucial function in many applications [34]. This task becomes intricate due to multiple considerations. Beam wandering, which is produced by external disturbances including atmospheric turbulence, wind, and heat fluctuations, necessitates immediate modifications to ensure the beam remains correctly directed onto the receiver plane. To meet these dynamic changes, the control system must include advanced algorithms and highly responsive actuators. Furthermore, the presence of non-linear characteristics in opto-electronic components, such as mirrors and lenses, adds complexity to the control process. The correlation between control inputs and beam adjustments is not direct, requiring the use of models and tactics that can anticipate and counterbalance these non-linear effects. Moreover, the presence of hysteresis in these components, which denotes the time lag between input signals and the corresponding beam changes, necessitates the system to employ predictive or adaptive algorithms to account for these delays. To maintain stability and precision in controlling non-linear systems, sophisticated methods such as nonlinear feedback control, adaptive control, or robust control are employed. Moreover, the system must be capable of efficiently managing sensor data and control algorithms through high-performance computing in order to handle real-time data processing. In summary, the intricacy of developing an ATP control system for FSOC systems derives from the presence of non-linearities and hysteresis. This necessitates the use of sophisticated control algorithms to ensure accurate beam alignment and stability [35]. The most significant disadvantage of the FSOC system is related to atmospheric factors. The system is intended to function in a turbulent atmosphere with randomly fluctuating Wind speed (Ws), Temperature (T), Relative Humidity (RH), and Pressure (P). These factors collectively contribute to fog, rain, snow, cyclones, air depressions, thunder, and lightning [36]. In FOC access points are connected by the radio frequency cable and microwave cable. There are many disadvantages in the FOC it has high cost because we have to pay for the band, there is issue of security also. these disadvantages we can overcome by using the FSOC. So the FSOC is centric connectivity's future frontier [37].

FSOC employs a range of modulation techniques, including amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM). These techniques are fundamental analog modulation methods. The On-Off-keying (OOK) modulation method, which is a technique for intensity modulation, was widely utilized in earlier research due to its simplicity in modulation and demodulation and its efficient use of bandwidth. However, the ability to endure. Specifically, air turbulence has a minimal effect in modulating OOK. Unlike standard Phase modulation, intensity modulation/direct detection (IM/DD) offers higher sensitivity and unique properties that make it more ideal for wavefront correction technology and FSOC systems. While not compulsory, it is advantageous in reducing air turbulence. This study will explore various modulation techniques, including on-off keying (OOK), binary phase shift keying (BPSK) etc. [30].

1.1 Application of FSOC:

- The FSOC technology has a broad range of applications because it can deliver fast, secure, and dependable wireless communication. Here are few important uses of FSOC:

1. **Telecommunication Infrastructure Backhaul Links:** FSOC is utilized for interconnecting network nodes in telecommunication infrastructure, specifically for establishing connections between cell towers and base stations. It offers a high-capacity, high-speed alternative to wired connections, which is especially beneficial in metropolitan settings where the installation of cables is difficult or costly. Enterprise Connectivity: Businesses

employ FSOC for high-capacity connections between buildings or campuses, particularly in situations where the installation of fibre optic cables is not practical owing to financial or logistical limitations.

2. **Networks for urgent and provisional purposes:** In disaster recovery situations where conventional communication infrastructure has been Broken, FSOC is extremely beneficial. The rapid deployment capabilities of this technology enable swift restoration of communication lines in impacted regions. For transient occurrences such as festivals, trade exhibits FSOC offers a rapid communication solution that can be swiftly established and disassembled thereafter.

3. **Military and Defence**: Enhanced Security for Communication: FSOC provides secure communication links by utilizing narrow beam and line-of-sight requirements, which significantly reduces the chances of interception or jamming. This is crucial for military operations where secure communication is important.

4. **Space Communications:** Intersatellite Links: FSOC is used to provide communication between satellites in space. FSOC allows for high-speed data transfer, which is crucial for satellite networks and space missions. FSOC technology enables high-data-rate communication between spacecraft and ground stations, which is crucial for deep-space missions. It facilitates the transfer of massive volumes of scientific data during these missions.

5. **Data Centres and Cloud Services:** Data Centre Interconnects: FSOC linkages between data centers can offer fast and efficient connections that supplement existing fibre optic networks, improving data transfer speeds and minimizing delay. Cloud Computing: FSOC facilitates the connection between cloud service providers and their clients or between data centers, hence enhancing the speed and efficiency of cloud-based services.

6. **R&D (Research and Development):** Scientific Research: FSOC is utilized in diverse research applications that necessitate rapid data transmission, including telescopes, particle accelerators, and other scientific apparatuses. Experimental Networks: Researchers employ FSOC to evaluate novel communication technologies and protocols in controlled settings, capitalizing on its capacity to provide high data rates and adaptability.

7. **Urban and Rural Connectivity:** Addressing the Digital Divide: FSOC technology can offer fast internet connection to urban and rural regions that lack or cannot accommodate traditional infrastructure. This facilitates the expansion of connectivity to rural or less easily reachable areas.

8. **internet Access:** Last-Mile Connectivity: FSOC can be utilized to provide fast internet access directly to end-users, particularly in regions where fiber-to-the-home (FTTH) or other wired alternatives are unavailable [38].

1.2 History in communication

Historical means of FSOC include signalling using beacon flames, smoke, ship flags, and semaphore telegraph. FSOC systems have initially gained interest as an effective solution for the "last mile" issue, which will connect the end user with the existing fiber optic infrastructure. Since ancient times, sunlight has also been utilized for long-distance signalling. Ancient Greeks and Romans used the sunlight for communication, employing polished shields to transmit signals by reflecting sunlight during fights. In 1810, Carl Friedrich Gauss devised the heliograph, a device that utilizes a pair of mirrors to precisely redirect a focused beam of sunlight onto a remote station. The original heliograph, initially it is used for the survey which is based on the earths shape and various parameters, FSOC was widely employed for military applications in the late 19th and early 20th century. Alexander Graham Bell created the photophone in 1880, which was recognized as the initial wireless telephone system in the world. The transmission relied on the modulation of a mirror's vibrations by the voice. The vibrations were reflected and radiated by sunlight, ultimately being converted into sound at the receiver. However, the military's interest in photophone continued. In 1935, the German Army created a photophone that utilized a tungsten filament lamp equipped with an infrared transmitting filter as its light source. In addition, military laboratories in the United States and Germany persisted in advancing the progress of high-pressure arc lights for optical communication until the 1950s. Currently, FSOC use lasers or light emitting diodes (LEDs) as transmitters. In 1962, MIT Lincoln Labs constructed a prototype FSOC connection utilizing a GaAs diode that emits light. This ground breaking experiment successfully sent television signals across a span of 30 miles. Following the creation of the laser, it was anticipated that FSOC would become the primary field for laser deployment, leading to several experimental efforts. Shortly after the initial public revelation of the functional laser in July 1960, scientists from Bell Labs successfully sent messages over a distance of 25 miles using a laser made with a ruby crystal. A thorough compilation of FSOC demonstrations conducted between 1960 and 1970, utilizing various laser types and modulation methods, can be found here. However, the outcomes were generally unsatisfactory due to significant divergence of laser beams and the incapacity to handle atmospheric influences. Following the advancement of low-loss fiber optics in the 1970s, they quickly became the preferred option for long-distance optical transmission, leading to a decrease in attention towards FSOC systems. FSOC systems utilize highly focused laser beams with a small diameter. The FSOC technology operates at a frequency over 300 GHz, which is globally unregulated. FSOC systems are highly deployable and can be reinstalled without incurring the expenses associated with dedicated fiber optic connections [1]. Naval boats have communications for safety and security connected due to INMARSAT's assessment and requirement. Japan established a public automated mobile network in 1981. In 1982, a restricted and secure internet data transfer protocol was implemented for emergency services, corporations, and university researchers [39].

Thanks to the discoveries and achievements in the field of telecommunication, technology has experienced significant evolution, progressing through various generations. The government activities and corporate contacts concerning telegraphy systems are undergoing rapid and frequent transformations in the terrain. The emergence of instant communication technologies has the ability to greatly influence different elements of human everyday life and its modernization in a good way. An important advancement in this field is the incorporation of several services into a single mobile device, known as the 'internet telephone,' which utilizes optical beam technology as a primary carrier. This growing trend is a central focus of current study and is increasingly acknowledged as an essential requirement for future progress. The IP telephony network is a notable departure from traditional telephone networks as it offers services that rely on the Voice over IP (VoIP) communication protocol. This novel method allows for the transmission of voice signals as data packets using current broadband internet connections, effectively substituting conventional telephone service systems with a more economical option. The widespread acceptance of IP telephony can be attributed to its capacity to provide services at a reduced cost while utilizing existing infrastructure. Furthermore, the increasing need for highcapacity backhaul and mobile-backhaul network solutions has emphasized the significance of adaptable broadband FSOC data connections. These advanced FSOC systems are specifically engineered to tackle the difficulties presented by the rising number of cell-sites that require high bandwidth and the escalating connectivity demands inside each cell-site. These factors are crucial for the effective implementation of next-generation 5G mobile networks. When it is difficult to create a direct line-of-sight (LOS) high-speed connection, other options including satellite, space-borne, or unmanned aerial vehicle (UAV)-assisted FSOC links can be used to stay connected with ground stations. Recent research highlights the practicality of FSOC (FSOC) data lines reaching speeds of up to 400 Gbps, especially for high-altitude platforms (HAPs). The possibility of using HAP-satellite backhaul lines strengthens the practicality of these advanced connectivity technologies, suggesting encouraging progress for future telecommunication infrastructures [40].

2. WHY MODULATION REQUIRED

50 years ago, there was no need for a modulation theory. The problem of conveying voice or music using radio waves has been resolved. The majority of the physical concerns encountered were understood. The persons who were applying these notions were lucky to have access to a wide range of frequencies that they could easily exploit. Outer space is known for its profound silence and huge extent, similar to the vastness of the ocean. Presently, the situation has undergone a metamorphosis. The growing need for more channels has reached its maximum capacity. Amplify this previously subdued range of frequencies, which we currently have. Multiple transmitters emit substantial power in various mediums such as television, voice, radar, and control. Signs or symptoms that suggest a particular condition or treatment. Without a doubt, we are very near to the famous. The scenario portrays a cocktail gathering where every individual is in attendance. He raised his voice in an effort to overpower the background noise created by other people. Man-made noise, also referred to as manufactured interference, is a prevalent occurrence in contemporary telecommunication. Poses a substantially graver concern than the small atmospheric disturbances we encountered. Encountered in the early phases of telecommunication. Presently, we are obligated to participate in the investigation of modulation theory. Moreover, with increased gravity, the goal is to improve the efficacy of transmitting information signals.

Prior to modulation, we solely transmit the information signal, which is a low-frequency signal. However, this approach has several drawbacks. Transmitting these low-frequency signals leads to signal attenuation, resulting in insufficient signal strength for longer durations. When using baseband signals without modulation, multiplexing was not employed, rendering long-distance signal transmission difficult. In order to send the signal across a greater distance, it is necessary to use a high frequency signal. Modulation involves combining the message signal with the carrier signal, which is a high frequency signal. One of the parameters of the carrier signal is adjusted based on the information signal. Modulation enables the transmission of signals over greater distances. Multiplexing allows multiple signals to be transmitted simultaneously through a single channel, reducing the need for multiple wires. By transmitting information on different carriers, signal mixing is avoided [41].

3. WHAT IS MODULATION

Many studies have been conducted on the various transmitter modulation formats to find the most effective electrical signals or information to send into air channels [42]. The baseband signal as received from the information source represents the original signal's frequency range. To effectively utilize the communication channel, it is necessary to convert the baseband frequencies into a different frequency range that is appropriate for transmission and then convert them back to their original frequency range upon receiving [43]. Baseband signals generated by different information sources may not always be appropriate for direct transmission across a specific channel. Typically, these signals undergo additional modifications to make transmission easier. In the modulation process we add the carrier which is a high frequency signal in the information signal. The act of transmitting information by superimposing it over a high frequency carrier signal is known as modulation. Modulation involves altering a single parameter of the carrier signal to convey the information signal [44].

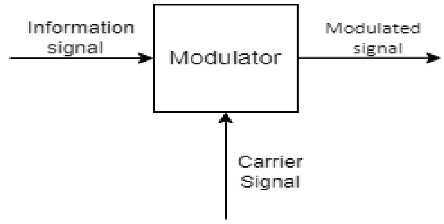

Fig.1 Modulation process [43].

The figure 1 shows the modulation process. The baseband signal is known as the modulating signal. the output we get after doing the modulation process is known as modulated signal [43].

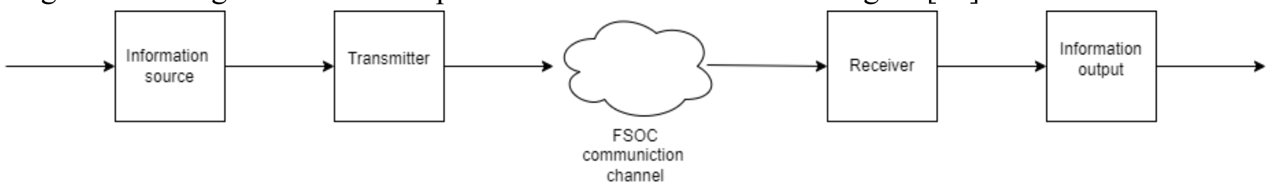

Fig.2 FSOC Communication Block diagram [44].

The fig comprises the message source, transmitter, channel, and receiver. The information to be sent, which might be in the form of sound, video, or data, is initially modulated using various digital modulation schemes such as on-off keying (OOK), pulse position modulation (PPM), and phase shift keying (PSK), among others. Subsequently, the signal containing information is electronically manipulated to adjust the intensity of the laser beam. Next, a transmitting telescope is employed to project the laser beam, which carries modulated information, into an unguided medium in order to propagate it towards the receiver. During the propagation of the signal, various types of noise are introduced, including Additive White Gaussian Noise (AWGN), sky radiation, and others. A receiving telescope is employed at the end of the communication system to capture the optical signal. Subsequently, a photodetector converts the signal from optical to electrical form [45]. Optical spatial modulation OSM is frequently used in FSOC communication systems to enhance the spectrum efficiency [46]. The modulation technique used in FSOC differs from that used in RF communication. Currently, the most practical method of modulation is intensity modulation (IM), in which the desired waveform is encoded onto the instantaneous power of the carrier signal. On the receiving end, the most pragmatic approach is direct detection (DD), in which a photon detector generates the desired outcome. The current is directly proportionate to the power received at any given moment. The dependence on intensity modulation/direct detection (IM/DD) will may greatly influence the design of a pixelated optical system [47].

It is important to understand that the sent signal is always positive and cannot have negative values. The magnitude of the sent signal, which carries the information, is always non-negative. Hence, the modulation coefficients need to be adjusted in a manner that ensures the signal adheres to a non-negativity condition. The RF modulation scheme differs from the mentioned scheme in terms of the coefficients used, such as those for a specific purpose. Quadrature amplitude modulation (QAM) is a sophisticated method that represents the amplitude and the phase of the signal. There are several distinct types of modulation techniques that are appropriate for Free Space Optical (FSOC) communication systems. Given the average optical emissions Power is constrained and the various modulation techniques are often evaluated based on their comparative characteristics. The average received optical power needed to achieve a desired Bit Error Rate (BER) at a specific point Data rate refers to the speed at which data is transmitted or processed. Maximizing power efficiency is desirable when selecting a modulation strategy. The ratio between the maximum power and the average power. Intensity modulation and direct detection Currently, intensity modulation with direct detection (IM/DD) is considered the most practical modulation approach in optical wireless communication (FSOC) systems. The most prevalent methods are binary-level due to their simplicity and cost-effectiveness Executions. Alternative intricate systems can offer superior bandwidth efficiency. Considering the trade-off between power efficiency and robustness. Various modulation approaches Various proposals and analyses have been conducted for FSOC (FSOC) communication systems. Each modulation scheme possesses unique characteristics and suitability for various applications. The key parameters that need to be compared among different modulation schemes are as follows:

1. Energy efficiency

This is a crucial factor to consider, as it directly relates to the amount of optical power that is currently accessible. The transmission is restricted because to concerns over eye and skin safety, as well as economic limitations. The process of modulation Schemes are often evaluated based on the necessary average optical power or Signal-to-noise ratio (SNR) is necessary to achieve a specific level of error performance at a particular data rate.

2. Optimal utilization of available network capacity

The bandwidth of an FSOC communication system is ultimately constrained by the capabilities of its subsystems, including the photodetector and the multipath channel, which can introduce limitations. In a medium with reduced visibility such as fog, aerosols, and other scattered/non-direct paths of light hyperlinks. Therefore, selecting the appropriate modulation type is crucial in order to achieve optimal bandwidth efficiency.

3. Ease and affordability of implementation

When considering modulation, it is vital to additionally take into account the FSOC communication system plan. Channel-induced dispersion and external noise can occur in certain settings. It is important to evaluate the sources under which the FSOC (Floating Storage and Offloading) system needs to be operated. As already stated Prior to this, the strength of an optical source is adjusted in order to convey a signal. Digital Data transmission involves two main processes: source coding, which refers to data compression, and channel coding, which deals with error correction. The process involves detecting and correcting errors, as well as efficiently combining different digital information streams. Data can be transferred either using binary encoding, where it is sent bit by bit, or using bit-word encoding. Block encoding is a fundamental concept. Below, we will explore some commonly used modulation methods for FSOC communication systems [48].

4. DIFFERENT MODULATION TECHNIQUE

4.1 On-off keying (OOK) :-

On-Off Keying (OOK) is a widely used modulation format in Free-Space Optical (FSOC) communication systems due to its simplicity and robustness in handling nonlinearities that can occur with laser sources. OOK is a form of binary amplitude-shift keying (ASK) that encodes binary data by varying the presence or absence of optical pulses [48]. We have employed the widely recognized method known as off keying non return to zero (OOK-NRZ). By altering the existing rolling, we can directly provide input data in this. The beam needs to be directed toward the receiver side via the telescope or lens. FSOC transmission is mostly utilized for large data rates, such as gigabit data connections, however LED technology can also be used for inter-building communication [49]. This modulation technique is particularly suited for Optical Wireless Communication (FSOC) because it effectively utilizes the binary nature of data transmission and the straightforward implementation of its signalling methods. In OOK, binary data is represented by the presence or absence of an optical pulse. Specifically, the transmission of an optical pulse at its highest intensity corresponds to the digital symbol "1," while the absence of a pulse signifies the digital symbol "0." This modulation scheme is known for its ease of implementation, making it ideal for various communication scenarios where simplicity and reliability are crucial. The OOK

modulation scheme can be implemented using either Non-Return-to-Zero (NRZ) or Return-to-Zero (RZ) pulse formats, each having its own characteristics. In the NRZ format, the optical pulse has a constant peak power, denoted NRZ-OOK is a modulation scheme the optical pulse has a peak power of $\alpha e P_r$(α_e =Optical source extinction ratio,$0 \leq$
$\alpha_e \leq 1$). and 1 indicating complete extinction of the pulse when transmitting a "0" symbol. In NRZ-OOK, the optical pulse is transmitted continuously at its peak intensity when a "1" is being sent, and no pulse is transmitted during a "0." This allows the receiver to distinguish between the two binary states based on the presence or absence of the optical signal. On the other hand, the RZ format involves pulses that return to zero intensity between symbols, providing additional time for signal recovery and potentially improving noise immunity. The simplicity of OOK modulation extends to the transmitter and receiver hardware required for its implementation. The transmitter typically consists of a laser source or LED that generates optical pulses corresponding to the binary data, along with modulation electronics that control the on-off switching of the optical signal. The receiver generally comprises a photodetector that converts the received optical pulses into electrical signals, which are then processed to recover the transmitted binary data. Overall, On-Off Keying (OOK) offers a straightforward and effective approach to optical communication in Free-Space Optical (FSOC) systems, leveraging its binary amplitude modulation to facilitate reliable and efficient data transmission over free space [48].

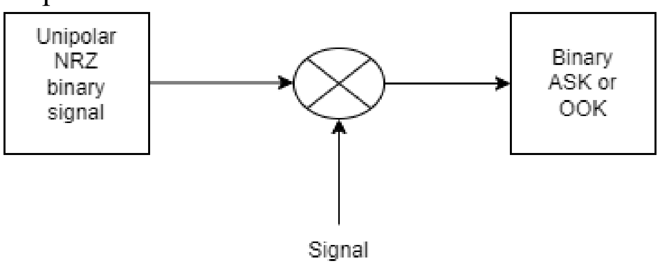

Fig.3 Blok diagram of OOK (Binary ASK) [48].

The symbol's optical signal energy can either be present or absent. At the receiver, the choice to interpret a received signal as either "1" or "0" is based on whether the energy of the received symbol is higher or lower than a predefined threshold. The bit rate, represented by $R_b = 1/T_b$ where T_b is the bit duration. Which is directly linked to the frequency at which the transmitter optical source is turned on and off. The transmit pulse shape for on-off keying (OOK) is represented by equation in a normalized form.

P(t)= {1, for t ϵ [0,T_b]
0}, elsewhere

On-Off Keying (OOK), or binary Amplitude Shift Keying (ASK), is a modulation method in which the amplitude of a carrier signal is adjusted based on the transmitted data, while the frequency and phase stay unchanged. In the binary Amplitude Shift Keying (ASK) modulation scheme, a digital "1" is transmitted by a carrier wave with a predetermined amplitude, while a "0" is indicated by either decreasing the amplitude or, in the case of On-Off Keying (OOK), totally disabling the carrier signal. This method streamlines the modulation process by employing only two discrete signal states: the existence or nonexistence of the optical pulse. Within the realm of Free-Space Optical (FSOC) communication systems, the main goal is to optimize the data rate while achieving the maximum distance with low mistakes. In order to accomplish this, the system depends on converting electrical data signals into optical signals through the use of a modulator. In the OOK (On-Off Keying) modulation scheme, a binary "1" is conveyed by the transmission of an optical pulse, whereas a binary "0" is indicated by the absence of an optical pulse. The data rate of a FSOC (FSOC) link is determined by the transmission rate of binary digits ("1s" and "0s"), which corresponds to the frequency at which pulses are sent and detected [50].

An optical-to-electrical converter, such as a photodetector, is employed at the receiver end of the FSOC (FSOC) link to transform the incoming optical pulses into electrical signals. The signals are subsequently analysed by a decision circuit in order to differentiate between the sent binary digits. This procedure entails the identification of the presence or absence of a pulse, thereby enabling the retrieval of the transmitted information. In the digital communication system encodes information into binary symbols, known as bits, and transmits them as modulated optical signals. The encoding process occurs at the level of individual bits, with each bit being transmitted as one of two distinct optical states. In direct detection (DD) systems, the usual binary technique is intermittently activating an optical source, such as a laser or LED, either in "on" or "off" state based on the data bit. OOK is a particular variant of this technique in which the optical source is either fully activated (representing a "1") or totally deactivated (representing a "0"). During OOK decoding at the receiver, the task is to ascertain if the received signal within a designated time interval has an adequate amount of optical energy to represent a "1," or if it is lacking, indicating a "0." The decoding process's performance is significantly affected by the selected threshold, which maximizes signal decoding accuracy while decreasing the likelihood of bit mistakes. The Bit Error Rate (BER) is determined by comparing the received data to a predetermined threshold, and it quantifies the probability of mistakes occurring in the received data. The selection of the channel model for an FSOC communication system employing Intensity Modulation (IM) is determined by the prevailing ambient light conditions. In situations when there is limited ambient light, the signal that is received can be represented as a Poisson process. This process is influenced by both the immediate optical power of the signal and any existing background light. When the background light is insignificant, the channel functions at its highest level of quantum efficiency. Nevertheless, when there is considerable background noise, the shot noise of the wideband photodetector can be precisely depicted as the combination of additive white Gaussian noise (AWGN) and a direct current (DC) offset. The transmit pulse form for On-Off Keying (OOK) is usually normalized in an Additive White Gaussian Noise (AWGN) channel without turbulence. In the demodulator, the incoming pulse undergoes integration over a single bit period and subsequent sampling. The given sample is evaluated against a predetermined threshold in order to determine whether it corresponds to a "1" or a "0". The receiver that is designed to minimize the bit error rate (BER) is referred to as the maximum likelihood receiver. This receiver employs a probabilistic approach to determine the chance of the received signal matching the transmitted symbols, taking into consideration detector noise and other sources of random noise. Both the signal and noise characteristics have an influence on the photocurrent in an OOK system. Therefore, accurately determining the photocurrent is crucial for maximizing system performance and obtaining a low BER [51].

$$P_{\gamma}(e) = \mathrm{BER} = \frac{1}{2\mathrm{erfc}\left(\frac{\mathrm{i_S}}{2\sqrt{2\sigma_\mathrm{n}}}\right)} = \frac{1}{2erfc\left(\frac{SNR_0}{2\sqrt{2}}\right)}$$

Where erfc(x)is complimentary error function defined by

$$\mathrm{erfc}(x)=\frac{2}{\sqrt{\pi}}\int_x^\infty e^{-u^2}\,du$$

and

$$\mathrm{SN}^{R_0} = \frac{i_S}{\sigma_n} = \mathrm{R}\frac{\rho_S}{\sigma_n}$$

Related work: -

1. The goal of the FOLC project is to create and test an EBB model of the optical communication chain in a lab setting using primary components that have been chosen for potential use in space travel. In collaboration with iXBlue and CILAS, Airbus Defence and Space created an engineering breadboard (EBB) model of an optical communication chain that can handle differential phase shift keying (DPSK) and non-return to zero (NRZ) on-off-keying (OOK) modulations at 10 Gb/s and 25 Gb/s. A 5 W optical booster, an optical transceiver (Tx/Rx), and a digital processing unit (DPU) make up the EBB. The technology known as wavelength division multiplexing (WDM) is employed to enhance the overall data rate. EBB, specifically how well the NRZ-OOK and NRZ-DPSK modulations operate for three 25 Gb/s channels. Measurements show that inside the 5 W-booster, non-linear effects begin to manifest. Compared to NRZ-OOK, the NRZDPSK signal is less susceptible to non-linear effects associated with power modulation due to its continuous envelope throughout bit time. For bit error ratio (BER) at 10-3, the average sensitivity of the NRZ-OOK and NRZ-DPSK lines at 25 Gb/s are -36.8 dBm and -40.2 dBm, respectively. FOLC consist of the three-part DPU, Optical transreceiver and Optical booster. In the DPU To calculate the BER, the DPU creates pseudo-random binary sequences (PRBS), which it then analyses after the transmission. The next stage will be to incorporate bit-level interleaver and FEC. The goal of FEC based on LDPC codes is to maximize performance while reducing onboard power consumption. The Virtex UltraScale board (XCVU095-2FFVA2104E device) serves as the foundation for the DPU-Tx and DPU-Rx subsystems. This device was selected because it offers multiple in/out ports, enough DDR4 memory to handle interleaving over huge blocks, and the ability to manage multiple channels at 25 Gb/s via a GTY 30.5 Gb/s transceiver. Furthermore, the 20 nm UltraScale technology utilized for this FPGA is the same as the one that Xilinx is presently using for space qualification (Kintex 60). The next is the transreceiver it is made up of the electro-optic transmitter and opto-electric receiver. Twelve distributed feedback (DFB) lasers are used in the system, producing seven uplink wavelengths (1539.77 nm to 1549.32 nm) and five downlink wavelengths (1556.55 nm to 1563.05 nm). The International Telecommunication Union (ITU) has designed a grid of 200 GHz on which these wavelengths are spaced. Because the system runs in half-duplex mode, uplink and downlink can only be evaluated in sequential order rather than concurrently. With careful consideration of factors such as multiplexer/demultiplexer misalignment tolerance, thermal stability of the DFB lasers, and the Doppler effect caused by the platform's high velocity at a 1500 km altitude in low Earth orbit (LEO), each channel has a 3 dB bandwidth of 96 GHz, chosen to support optimal transmission of 25 Gb/s signals. Only three wavelengths are modulated simultaneously in order to study cross-talk. The system's modulator slice consists of radio frequency (RF) drivers and Mach-Zehnder modulators (MZMs) for the modulation formats Differential Phase Shift Keying (DPSK) and On-Off Keying (OOK). The same MZM is used to generate both modulations, but different RF drivers and bias voltages are used. The third part is the Optical booster 5 W booster is utilized to facilitate communications across extended free space distances. The architecture of the double-amplification stage was selected to provide flexibility over the flatness setting. Through the collimator, the booster output is routed to the optical channel emulator. Using optical densities, the 5 W-collimated beam is attenuated by a factor of 100 to maintain a tolerable optical power on the remaining free-space bench. A tracking sensor detects a portion of the optical beam and uses it to provide feedback to the tip-tilt mirror, which keeps the fiber injection going. The power that reaches the optical receiver is adjusted following injection using a variable optical attenuator (VOA). There are multiple steps involved in measurement. The transceiver is tested separately first. Subsequently, the transceiver's performance and the DPU are assessed. The booster has now been added to the URL. This test series enables the assessment of each component's

contribution to the overall performance. 3x 25 Gb/s channels have been sent simultaneously, and the performance of NRZ-OOK and NRZ-DPSK has been measured. With a BER of 10^{-3}, the average sensitivity of the entire bread board at 25 Gb/s is -36.8 dBm for OOK and -40.2 dBm for DPSK. There has already been work done to improve the DPU characteristics and DPU to transceiver connections in order to raise these sensitivities. Gains of up to 1.5 dB and 2 dB should be available for DPSK and OOK modulations, respectively. Compared to OOK, the DPSK sensitivity is around 3.4 dB higher. Measurements show that inside the 5 W-booster, nonlinear effects begin to manifest. Compared to OOK, the DPSK signal is less susceptible to non-linear effects associated with power modulation due to its consistent envelope throughout bit time. For low BER, a method based on unevenly spaced WDM channels has been suggested to lessen the impact of non-linear effects. The inclusion of an optimized FEC and interleaver to reduce air turbulence is the next stage of the EBB project [52].

2. In this experiment they observed that recently, there has been a lot of interest in multi-point free-space optical communication (FSOC) as a useful method for boosting capacity in the next generation of communication networks. For the purpose of identifying the number of users, a method based on histogram peak detection and unsupervised machine learning such as k-mean, k-medoid, hierarchical, and fuzzy clustering is suggested and experimentally shown. The amplitude data of the received signals is necessary for the suggested methodology to function. The findings indicate that under-estimation of the number of users is shown when many users' signals are received with similar loudness; as a result, a new strategy weighted clustering was used and experimentally confirmed. The work presented below showed that the suggested methodology can detect numerous transmitting users in real time and under extreme atmospheric turbulence simultaneously and accurately. Non-return-to-zero (NRZ) OOK modulation was used as the modulation strategy. When deploying OOK with one user, two possible optical outputs are expected: PT (transmitted power) when “1” is communicated and αePT (αe = optical source extinction ratio $0 < \alpha e \leq 1$) when “0” is transmitted. When N users transmit at the same time, the feasible optical power outputs are $k = 2N$. As a result, the receiver side will detect k power levels. On the other hand, if N= log2k power measurements are found, the number of transmitting users can be obtained as log2k. Therefore, we suggest that power levels from the received mixed signals be extracted using clustering algorithms, after which the number of broadcasting users can be determined. To calculate the number of predicted clusters that would be entered into clustering algorithms, pre-processing of the data was necessary. After that, four clustering techniques were assessed: fuzzy, hierarchical, K-mean, and K-medoid. In order to account for underestimation in cases where users' amplitudes received at the receiver were of equal power, a weighted clustering analysis was finally performed. Although scenarios with one, two, and three transmitting users were investigated, three users case scenario outcomes will be provided hereunder. the application of unsupervised learning to transmitting user detection in real-time into an omnidirectional, multi-user FSOC receiver. An analysis of pre-processing provided support for the clustering algorithms, which were then tested experimentally. The suggested approach is dependent on the transmitted signals' amplitude data that is gathered at the receiving end. To address the underestimation of the observed user count when users are received with equal power values, a weighted clustering technique was suggested. The suggested technique can accurately estimate the number of transmitting users even when there is significant atmospheric turbulence, as demonstrated by the experimental findings [53].

3. The beam steering approach of a propagating laser beam is described in this study, which is crucial for the coupling of Free-Space Optical Communication (FSOC) to Single Mode Fiber (SMF). Using a low-cost Fast Steering Mirror (FSM) that was produced, the arrived laser beam's displacement (tilt) is dynamically adjusted. The displacement is monitored using an instantaneously developed Position Sensitive Detector (PSD). In order

to increase the efficiency and coupling dependability, the FSM has slanted about the azimuthal and elevation axes. In our Laser Communication Laboratory, we are able to tilt the FSM for approximately 8.5 mrad. (LCL). Performance of the created steering system is tested in the real time FSOC link. The experimental test-beds are located at transmitter and receiver locations that are 500 meters apart horizontally and 15.5 meters above the earth's surface. The components of the transmitter laboratory are the following: (i) Data generator; (ii) Optical modulator; (iv) Laser source; and (v) Beam expander. The Xilinx Spartan 3 Field Programmable Gate Array (FPGA) is designed to implement a high-speed parallel Linear Feedback Shift Register (LFSR) architecture. The FPGA is powered by an externally connected 160MHz clock signal, which creates a serial pseudo random binary sequence (PRBS) as the data pattern. The optical modulator circuit receives this PRBS sequence serially in order to modulate the 10mW, 850 nm laser beam. The PRBS data sequence is processed at the optical modulator using the On-Off Keying (OOK) modulation and Direct Detection (DD) technique at an ATM rate of 155Mbps. The primary side of the beam expander receives the modulated laser beam, which extends the beam diameter by a factor of three, or from 3 mm to 9 mm. The purpose of this device is to enhance the output beam diameter, which reduces or restricts the beam divergence at the receiving telescope's aperture. The horizontal route is taken by the 9mm modulated beam as it gets to the receiver. The two most significant factors impacting FSOC performance are climatic impacts and building sway. The main atmospheric elements that have an impact on the beam's quality during its propagation route are discussed and explained. Technical specifications are provided for the experimental test-bed created for the FSOC transmitter and receivers. The low-cost PSD and FSM's construction and design are highlighted. The FSM and PSD's interface and operation with the FPGA are described. Uniform for minute wave front tilt, the devised control system is not adequate to achieve fine steering in the order of micro radians to stabilize the laser beam. Enhancing the correction efficiency is necessary to reduce the inner scale beam wandering. In this experimental arrangement, the rapid fine steering mirror and four quadrant detector pair based on piezo-actuators can be preferred over the low-cost FSM and PSD that have been created. The FSOC will be more reliable than this system in terms of Power Stability, SNR, and BER after Adaptive Optics (AO) is incorporated [54].

4. This research describes the use of diffusers transmitter modulation in free space optical communication systems to lessen the impact of atmospheric turbulence. This method makes use of two transmitters and two receivers that detect utilizing differential mode. These elements work together to create a better modulation technique, particularly for lowering scintillation index, overcoming signal detection with a fixed zero threshold, and increasing power received. These three components are crucial to enhancing the free space optical system's performance. According to the analysis's findings, the propagation of 4.59dBm for receiving power dual diffuser modulation at 3 km distance is superior to the 7.6dBm of conventional OOK utilizing diffusers, which is equivalent to a 3dBm improvement or up to 40% better. As a model for a conventional system, the suggested system modulates the signal using On Off Keying (OOK) modulation. It makes use of two transmitters: transmitter B (which is configured in compliment condition) will emit bit '0' simultaneously with transmitter A when transmitter A sends bit '1', and vice versa. The subtractor will process the signals right away in order to find differential modes. In this method, the subtractor was assumed to be a perfect one with zero signal loss. As a result, bit '1' for binary input signal '1' and bit '-1' for binary input signal '0' represent the output signals, respectively. The binary transmitting process is shown in Table 1. As we can see, this modulation strategy did away with the requirement for an adaptive threshold, whereas traditional OOK modulation relies on threshold detection to identify if an incoming signal is a bit '1' or '0'. Conventional detection methods always result in

misinterpretation by the receiver, where noise alone can trigger as signal bit '1' (sending pulse), also commonly referred to as a "false alarm." Occasionally, data-containing signals are recognized as bit '0' (no pulse condition) when the signal falls below the threshold value. 'Miss detection' is a common term for this circumstance. In order to solve this issue, the complicated adaptive threshold has been proposed. However, with the use of dual diffuser modulation, the fixed zero threshold improves the precision of the detecting signal. One can use reference to ascertain whether the input signal is binary ('1' or '0'). Furthermore, we positioned a low-cost material phase screen diffuser at the transmitter to more effectively counteract the effects of atmospheric turbulence and provide the best possible overall system performance. In FSOC, this combination produces the superior robust modulation. Assuming that Yn is the received signal with zero threshold detection based on Table 1, The performance of free-space optical communication in the atmospheric turbulence channel is enhanced by the diffuser modulation. Scintillation index, power received, and signal technique—which used the partially coherent beam approach—all have a significant impact on BER in air environments. The partially coherent beam method improved power received by up to 40% and extended the BER distance by 42% when compared to standard OOK. Consequently, it produces a strong modulation with a fixed zero threshold value against turbulence [55].

Advantages of OOK

- Simplicity: OOK is easy to implement due to its binary nature, where the signal is either turned on or off. This simplicity results in less intricacy in the design of both the transmitter and receiver [56].
- Minimal Power Consumption: In OOK, the transmitter remains inactive when sending a '0', resulting in little power usage during these intervals. This can lead to substantial energy conservation, particularly in applications with low duty cycles.
- Economical: OOK is often more economical than more intricate modulation schemes due to its straightforward design and implementation. This feature renders it appropriate for cost-effective applications.
- Resilience in Specific Circumstances: OOK can exhibit resilience in circumstances characterized by a low signal-tonoise ratio (SNR). Given that the presence of a signal signifies '1' and its absence signifies '0', the system can function effectively even in the face of a weak signal.
- Suitable for limited Data Rates: OOK can be highly efficient for applications that have limited data rate needs, such as basic remote controls or sensor networks.
- Detectability: The existence or absence of a signal can be easily detected, making the demodulation process simpler.
- OOK is frequently employed in simple and outdated radio systems, ensuring compatibility with older technology and infrastructure.
- OOK is a reasonable option for certain applications that prioritize simplicity, power efficiency, and affordability over higher data rates or robustness provided by more intricate modulation techniques [48,50].

4.2 Pulse position modulation (PPM): -

Pulse Position Modulation (PPM) is a complex modulation technique used to improve the efficiency of transmission in Free-Space Optical (FSOC) communication systems. PPM is notable among baseband modulation techniques due to its capacity to enhance power efficiency, rendering it especially valuable in situations where reducing energy consumption is vital, such as in handheld devices and portable communication systems. Although PPM has its benefits, it also brings about increased bandwidth requirements and added intricacy when compared to more straightforward modulation techniques such as On-Off Keying (OOK). PPM utilizes the technique of encoding data by positioning a pulse inside a predefined time frame, as opposed to altering the amplitude or duration of the pulse. An L-PPM symbol is comprised of a solitary optical pulse that occupies one out of L time slots. Here, L is equal to 2 raised to the power of M squared, where M is a positive integer. For a given PPM system, the total number of time slots is a power of two. The remaining L-1 slots inside this symbol period are vacant, indicating that no pulse is transmitted during these periods. Data is sent by emitting an optical pulse with a non-zero intensity within one of the L time slots. Each slot corresponds to a distinct value that is directly linked to the delivered data. The data is encoded by using the position of the pulse within the slot sequence. Each group of log2M data bits is mapped to one of M potential positions. Consequently, the data is encoded based on the pulse's position rather than its amplitude or width. In an M-PPM system, each symbol is represented by a pulse with a constant power P filling one of the M time slots, while the remaining M−1 slots stay empty. The pulse's position is determined by converting the binary representation of the data bits into a decimal number, which corresponds to a certain slot. This encoding method enables a more energy-efficient transmission by ensuring that the optical pulse is only present in one of the slots and absent in the others. PPM can be implemented using two main methods: continuous and quantized. In continuous pulse position modulation (PPM), the temporal placement of the pulse is directly correlated to the magnitude of the information sample. Consequently, the timing of the pulse is continuously modified to accurately reflect the magnitude of the delivered data. The mathematical expression of a PPM wave with a duration τ can depict the relationship between the timing of the pulse and the encoded information. Pulse Position Modulation (PPM) provides improved power efficiency for optical communications, making it ideal for devices with restricted energy resources, such as handheld and portable devices. The technique's capacity to encode data by the placement of a pulse within a series of time slots offers a resilient and effective approach for conveying information, despite the elevated bandwidth demands and heightened system intricacy [57].

$E_M(t) = A_C Cos\omega_0 t \;\; for \;\; \text{tr} + \tau_d \leq t \leq t_n + \tau_d + \tau$

Where the time delay, τ_d of the leading edge of the carrier pulse with respect to the same time t_n, is

$\tau_d = \frac{\tau_p}{2}$ [1+M (t_n)]

Analog modulation systems involve the continuous variation of an analog information signal, denoted as M(t). Timesampling is a common practice in the majority of pulse-modulation systems to capture the information stream. the Pulse Position Modulation (PPM) of an analog signal in order to comprehend the digital signal in a PPM scheme, it is important to take notice of the precise location of the location of the pulse transmits the information. The average power can be expressed as pulse position modulation (PPM) An abbreviation for "advanced placement". L is defined as the pulse amplitude, where L is equal to 2M, and M represents the resolution of the input data bits. Consider the variable Rb. Determine the input data rate in order to calculate the PPM slot duration, Ts. The expression log2 L/LRb represents the logarithm of the ratio of L to LRb, using base2. Regarding For instance, if L is equal 4 and 22, then M would be equal to 2. The expression "Ts=log2" represents the logarithm of Ts to the base 2. The equation 4/4Rb is equivalent to 2/4Rb, which is also equivalent to 1/2Rb.a graphic depiction of the mapping process to a transmitter, specifically a laser. Power for 4-PPM format [37]. The diagram illustrates the mapping of binary patterns to pulse patterns in a 4-Pulse Position Modulation (4-PPM) system. It visually demonstrates how binary data is encoded into PPM symbols. This modulation system transmits information by precisely positioning a pulse inside a predetermined range of time slots. At the receiver, the encoded PPM signals are recognized using detection techniques that decipher the pulse positions to precisely extract the delivered data. PPM in FSOC systems has the benefit of eliminating the need for detection thresholds, hence simplifying the detection process in comparison to alternative modulation schemes. In power-limited FSOC systems, such those found in portable devices, raising the modulation level M typically results in a decrease in the average transmission power required to achieve the desired performance. The reason for this is that higher modulation levels enable a more effective dispersion of optical power across a larger quantity of time slots. Nevertheless, the impact of raising the modulation level on reducing transmitted power is weakened when atmospheric turbulence is present. Turbulence causes the introduction of extra noise and distortions to the signal, which counteracts the advantages in power efficiency achieved through greater modulation levels. Consequently, despite increasing M values, the decrease in necessary transmission power to uphold a certain Bit Error Rate (BER) becomes less notable in turbulent situations. In order to analyse the performance of the FSOC communication system under different levels of turbulence, it is crucial to estimate the average bit error rate (BER) for various modulation schemes. The M-array PPM approach is highly advantageous for this purpose as it enables a thorough examination of performance in conditions of moderate to significant air turbulence. In an Intensity Modulation with Direct Detection (IM/DD) Free-Space Optical (FSOC) system, the model consists of an optical source that communicates data by encoding it onto the instantaneous optical intensity of the signal. The signal traverses the turbulent atmosphere and is subsequently detected by a photodiode. The incoming signal, which is translated into an electrical signal y, is influenced by different forms of noise, such as shot noise and thermal noise. Both of these noise sources follow Gaussian statistics with a mean of zero. The system's performance, as indicated by the bit error rate (BER), relies on the receiver's capacity to distinguish various pulse locations amongst noise and turbulence. This ability determines the overall effectiveness of the pulse position modulation (PPM) system in ensuring dependable communication [58].

Related work of PPM: -

1. RZ-GMSK is a modulation scheme that adjusts for inter-symbol interference. Sahoo's investigation on its error performance revealed that it performs better than PPM and PPM-MSK, especially in bad weather and during high-speed transmission. Subsequent investigations with hybrid FSOC/FO linkages revealed marginal gains over conventional FSOC, with a range extension to 40 km. Adaptive methods were put forth to maximize spectral efficiency under turbulence with

PSK, enhancing SIMO and MRC approach performance. Research on multi-pulse PPM and WDM indicated ways to mitigate noise, atmospheric turbulence, and aiming problems; M-ary PPM was suggested as having superior sensitivity. Spectral efficiency was further improved by the application of spatial coherence variety and aperture averaging. Furthermore, various formats of electrical pulse generators were assessed in relation to power distribution and transmission performance for point-to-point optical communications. This paper investigates the performance of a highspeed point-to-point optical link (P2P-OL) system in FSOC-MIMO environments under log-normal fading (LNF) and Gamma-Gamma (G-G) turbulence channels utilizing an Electro-Optic Modulator (EOM) with an NRZ Pulse Generator

(NRZPG). The findings show that, in dust-fog situations and at different turbulence levels, FSOC-MIMO models perform better than SISO models. With beamforming, the system can withstand attenuation of up to 61.45 dB/km in a G-G FSOC9x9 channel and 62.6 dB/km in an LNF FSOC-1x1 channel. With 16 users, the WDM-P2P-OL system reaches 150 Gbps optical communication capacity [59].

2. The purpose of this article is to calculate the Bit Error Rates (BER) performance for viable deployments of free space optical communication (FSOC) under the atmospheric meteorological conditions of Namibia and South Africa. The Pulse Position Modulation (PPM) based BER performance model was used to calculate different BER values in a few selected localities in both nations in order to accomplish this goal. The findings

demonstrated that, on average, BER levels were lower in the winter than they were in the summer. In towns with high scintillation index values, BER increases quickly as photon count increases, according to a comparative investigation of several locations with the lowest and highest scintillation in both countries. The main focus of this study is on Pulse Position Modulation (PPM) Bit Error Rate (BER) analysis in Free Space Optical Communication (FSOC) systems. PPM is orthogonal modulation technique that is distinguished from conventional On-Off Keying (OOK) by its better power efficiency. Because PPM uses brief pulses with the same amplitude and width to transfer data, it is perfect for communication systems that are power-sensitive. PPM was selected for this investigation due to its effectiveness in reducing power consumption, which is an important consideration for optical systems in regions with fluctuating atmospheric conditions. The BER analysis concentrated on important sites in South Africa and Namibia, assessing the BER characteristics of these municipalities using a well-known PPM-based approach. According to the study, because of their low scintillation values, cities like Windhoek and Johannesburg have the lowest BERs in their respective nations. Over lengthier trips in these cities, BER grew gradually, only exhibiting notable spikes after 20–25 km. Towns like Walvis Bay and Cape Town, on the other hand, with higher scintillation values, showed significantly higher BER, with sharp increases in BER happening after just 5 km. Another important conclusion of the study was the effect of seasonality on BER. Temperature variations were shown to be a contributing factor in the observation that BER values were lower in winter than in summer. For example, dramatic temperature changes in Namibia's Ondangwa and Katima Mulilo towns resulted in a shift in BER of more than 60%. In the meanwhile, South These results led to the study's formulation of numerous crucial recommendations. By simulating FSOC links for internet traffic in network simulations, the BER values derived from this PPM-based research could offer insights into how PPM functions in different weather scenarios. The paper also recommends that in order to improve the performance of the FSOC system, alternative modulation techniques should be investigated and contrasted with PPM. Because the study was notably predicated on simulation results, the authors highly advise field testing with FSOC equipment in order to corroborate the simulation data. Lastly, the study hopes that by utilizing PPM to analyse BER performance, these results will stimulate future research into creating a low-cost link adaptation scheme for FSOC transceiver systems that is tailored to the particular atmospheric conditions seen in South Africa and Namibia. PPM, stands highlighted as a suitable modulation approach for such future developments because of its emphasis on power efficiency [60].

3. In this paper yidi chang done a experiment based on the FSOC system which uses the avalanche photodiode detector (APD) and compare the APD and PIN detection. In APD detection the average bit error rate is examined which uses the ppm by considering the fiber coupling efficiency as well as the gamma gamma atmospheric turbulence. Additionally, it is discovered that in Avalanche Photodiode (APD) detection systems as opposed to Positive-Intrinsic-Negative (PIN) detection systems, the influence of the Fiber coupling efficiency (FCE) on the ABER is more substantial. When compared to PIN systems, the communication performance of APD systems is significantly improved by the application of adaptive optics technology. It is noteworthy that there is a substantial correlation between the optimal APD gain and detector temperature, although there is a poor correlation with other aspects including receiving aperture size, FCE, average received photon number, and air turbulence intensity. The research indicates that more enhancements in the efficiency of APD-based communication systems can be attained through the optimization of reception aperture dimensions and the development of a precise temperature control mechanism [61].

4.3 Binary phase shift keying Modulation (BPSK): -

Phase-shift keying (PSK) is a modulation technique that changes the phase of a carrier signal in order to encode data. Binary Phase-Shift Keying (BPSK) is a basic type of PSK where two separate phases are used to represent binary digits. More precisely, one phase corresponds to the binary value "1," whereas the other phase corresponds to the binary value "0." The phases are distinct at 180 degrees, indicating that the carrier signal's phase switches between two angles when the input digital signal changes state. This phase shift directly corresponds to the transmission of binary data. FSOC (FreeSpace Optical) communication systems utilize subcarrier phase-shift keying (PSK) intensity modulation to implement BPSK. This method utilizes easily accessible and affordable microchips to carry out the modulation process. First, the digital data sequence is encoded using a phase shift keying (PSK) subcarrier. The PSK signal is subsequently transformed to an intermediate frequency (IF) that is appropriate for integration into the electrical circuit of the transmitter. This process of up-conversion enables the modulation of the signal to be controlled using current techniques of radio frequency modulation. After modulation, the optical intensity of the transmitting beam is modified based on the modulated electrical signal. Photodetectors are used at the receiver end to transform the optical signal received into an electrical signal. The electrical signal is demodulated utilizing RF equipment, such as steady oscillators and selective filters, in order to retrieve the delivered data. In a Binary Phase Shift Keying (BPSK) system employed for Free Space Optical (FSOC) communication, the phase of the output carrier signal switches between two angles that are 180 degrees apart whenever the input digital signal transitions between binary states, either from "1" to "0" or vice versa. The phase shift occurs at the points when the carrier wave crosses zero, known as coherent points. In order to achieve efficient demodulation of Binary Phase Shift Keying (BPSK), it is necessary to compare the received signal with a sine carrier that has the same phase. This requirement necessitates the system to possess the ability to retrieve the carrier phase and execute intricate circuitry to synchronize with it. The procedure initiates by modulating an RF sub-carrier signal with the source data, represented as d(t). The modulated signal is utilized to regulate the intensity of a continuous-wave (CW) laser diode, which serves as the optical carrier. The bias current given to the laser diode guarantees that it functions at or above the minimum current required for activation, maintaining the optical signal's proportionality to (m(t) and allowing it to transmit across the communication medium. In order to counteract atmospheric turbulence and reduce background radiation, an optical bandpass filter is placed immediately prior to the photodetector. This filter serves to eliminate the detection of ambient noise by the photodetector, ensuring that only the desired signal is detected. The obtained optical power is subsequently transformed into an immediate photocurrent, which signifies the electrical signal generated by the photodetector. The received signal is then subjected to processing in order to recover the transmitted data, while considering the impact of atmospheric turbulence and ensuring precise communication [62,63].

Binary Phase Shift Keying (BPSK) is a basic type of phase shift keying (PSK) modulation, in which the phase of a carrier signal is controlled by individual data bits. BPSK modulation involves shifting the carrier to one of two potential phases, which are 180 degrees or π radians apart, at each bit interval. The phase shift relates to the transmission of binary data, where one phase represents a binary '0' and the other phase represents a binary '1'. The Bit Error Rate (BER) for Binary Phase Shift Keying (BPSK) in an Additive White Gaussian Noise (AWGN) channel can be calculated using the formula

$$BER = \frac{1}{2} . erfc(\sqrt{\frac{E_b}{N_0}})$$

, where $erfc$ is the complementary error function, E_b is the energy per bit, and N_0 is the noise power spectral density.

The formula demonstrates that the Bit Error Rate (BER) falls exponentially as the Signal-to-Noise Ratio (SNR) increases, demonstrating improved performance when the signal strength is higher compared to the noise. The AWGN channel model, which assumes Gaussian noise with a constant power spectral density, is well-suited for satellite and deep-space communication systems because it accurately represents thermal noise. However, in the context of communication on land, this model lacks accuracy as it fails to consider variables like multipath propagation, terrain blocking, and interference. Although the AWGN model has its drawbacks in real-world terrestrial contexts, it is frequently employed to simulate background noise and establish a basic grasp of system performance before dealing with more intricate channel circumstances [64]. Related work: -

1. The "Clear1" model describes the high-altitude turbulence in terms of a refractive index structure. In the high-altitude turbulence channel, the outage and Bit Error Rate (BER) performance of fairborne communication links under atmospheric turbulence and aero-optic effects of homodyne binary phase shift keying (BPSK) system is deduced. The relationship between the probability of fade, mean fade time with flight altitude and transmission distance is analysed. The Bit Error Rate (BER) varies characteristically along with the mean signal noise rate signal al noise rate (SNR) of different modulates is explored in the gamma-gamma turbulence channel. The findings indicate that atmospheric turbulence and aero-optic effects can significantly lower the SNR that would arise in the absence of optimal turbulence, sometimes resulting in BERs that are tolerable. A homodyne BPSK-based modem was used to achieve a bit error rate of 5.94 at a propagation distance of 200 km, with an average SNR of 26 dB. Although a thorough examination of the advantages and disadvantages of various FSOC modem architectures is outside the purview of this text, a resilient FSOC modem should optimize the connection margin by having as low a receiver sensitivity as feasible to reduce the likelihood of link interruptions due to intensity fades. Regarding this, the best theoretical sensitivities can be achieved via hierarchical receiver topologies. Homodyne BPSK is a modulation system with excellent sensitivity for tracking and transmission when compared to other orthogonal modulation schemes. Furthermore, BPSK offers greater protection to sunlight than other modulation techniques. The "Clear1" model describes the high-altitude turbulence in this work in terms of the refractive index structure. We demonstrate the homodyne BPSK link performance for aerial communication while taking structural differences into account. Based on the gamma-gamma distribution, airborne link fading of optical signals is simulated. The study of the simulation result suggests some recommendations for minimizing the impact of turbulence on system performance. The "Clear 1" model uses refractive-index structure to explain the high-altitude turbulence. The bit error rate (BER) varies characteristic along with the mean SNR of different modulates is discussed in the gamma-gamma turbulence channel. The outage characteristic and BER performance of airborne communication links under atmospheric turbulence and aero-optics effects of homo-dyne BPSK system is deduced in the high-altitude turbulence channel. The relationship of probability of fade, mean fade time with f light altitude and transmission distance is analyseda. The findings indicate that: (1) the mean irradiance at 100 km propagation distance decreases by more than 12 dB, and at 200 km, it decreases by 17 dB. This allows for a probability of fade of 10 6. (2) Atmospheric turbulence and the aero-optic effect result in a 5 dB drop in FT at flight altitudes of 7000 m and 10,000 m, respectively, based on a mean fade time of 0.01 ms. (3) In a turbulence system, the average SNR increases by 10 dB for BPSK and 12 dB for OOK to achieve a BER of 10 6. To further improve free space optical communication's reliable performance, Strong turbulence can cause intensity swings, but modem architecture with a high-sensitivity receiver and high-dynamic range can handle them [65].

2. The proposed TED and Gardner's TED are compared for accuracy using the timing jitter in decibels (dB) as a parameter. It is defined as follows: 100 S-curves of Gardner's and suggested TED are obtained by scanning

the sampling phases on bursts of NRZ-BPSK signal with a block size of 512 samples and an OSNR of 6 dB. The variance of zerocrossing positions of the S-curves is normalized by the symbol period. It is evident that there is a relative drift, or jitter, in the zero-crossing point of the S-curves with time. The timing jitters measured at various OSNRs It is evident that the suggested TED and Gardner's TED are about equally accurate. The jitter is constant at OSNR = 0 dB. Low OSNR (−3 dB) is when the former has jitter that is only 0.8 dB higher. In order to address the urgent problems caused by the FSOC signals for the timing recovery technique—which is essential for the DCRs—we provide a multiplication-free blind TED algorithm. This method has more consistent output characteristics and a lower computation complexity than Gardner's TED. We create a parallel TRA that is appropriate for FSOC signals with a wide dynamic range and extremely low OSNR based on the suggested TED. Investigations are also conducted on how the parallelization factor, PLL delay, and SCO affect performance. Results from simulations and experiments confirm the benefits of the suggested TED and TRA over the traditional Gardner method [66].

3. The effect of atmospheric turbulence-induced fading on binary phase shift keying (BPSK) subcarrier intensity modulation (SIM) symbol detection accuracy in optical communication links—more especially for on-off keying (OOK) systems has been thoroughly examined by Popoola et al. The unpredictable variations in the received optical signal strength caused by atmospheric turbulence can cause signal fading, which in turn compromises the accuracy of symbol identification in communication systems. In a temperature-controlled lab setting, the researchers used a chamber with blowers and heating devices to replicate different turbulence situations. By precisely controlling air temperature and flow, these devices can replicate phase distortions and scintillation that are caused by atmospheric turbulence on an optical communication link. This configuration offers a perfect environment for assessing how well various modulation schemes—such as OOK and BPSK-SIM—perform in varied turbulence conditions. Next, under the different turbulence circumstances induced within the chamber, the bit error rate (BER) performance of both OOK and BPSK-SIM systems is examined as a function of the electrical signal-to-noise ratio (SNR). The study measures the turbulence-induced deterioration in communication quality for each modulation scheme by comparing the BER against SNR. The assessment offers significant understanding of how stable BPSK-SIM is in comparison to OOK when turbulence is present, which will help in the creation of optical communication systems that are more resilient [67].

4.4 Polarization shift keying (POLSK): -

Free-Space Optical (FSOC) communication is becoming increasingly popular as a feasible method for transmitting large amounts of data and providing wireless internet access across unlicensed optical frequencies. Historically, FSOC receivers have typically utilized direct detection (DD) techniques instead of coherent detection (CD) approaches. The fundamental reason for this preference is the difficulties in maintaining coherence between the signal and the local oscillator (LO) fields. Atmospheric turbulence can cause unpredictable changes in the strength and position of a signal, leading to distortions in the signal's phase and disrupting its spatial consistency [68].

While adaptive optical front-ends have the potential to address these problems, the practical implementation of these systems is currently challenging and not feasible for regular use. Intensity modulation (IM) is a frequently employed technique in Free-Space Optical (FSOC) systems to manage the natural variations induced by atmospheric turbulence. Intensity modulation (IM) offers a more resilient approach for managing these variations in comparison to coherent detection. On-Off Keying (OOK) is a commonly used digital encoding strategy in IM/DD systems. In the OOK encoding scheme, a binary digit 'one' is symbolized by a pulse, whereas a binary digit 'zero' is denoted by the absence of a pulse. The receiver has a threshold detection method to differentiate between the existence and nonexistence of pulses. Nevertheless, the performance of On-Off Keying (OOK) can be greatly affected when the received signal level fluctuates due to turbulence, as it requires the threshold level to be adjusted dynamically in order to retain the best possible performance. The need of constantly modify the threshold is a significant disadvantage of OOK, as the receiver must precisely ascertain the threshold level for optimal functioning. Polarization Shift Keying (POLSK) is an alternate encoding technique that does not depend on threshold detection. POLSK was initially suggested as a substitute for conventional encoding algorithms in the context of coherent detection optical communications. This method utilizes the polarization state of the electromagnetic wave carrier to encode information. Studies using POLSK modulation for direct detection systems have demonstrated an approximate 3 dB improvement in sensitivity compared to OOK modulation. Notwithstanding these benefits, POLSK encounters its own array of obstacles. The inherent birefringence of typical optical fibers leads to variations in the polarization state, posing challenges in accurately monitoring and restoring it at the receiver. Although it is feasible to recover the polarization information, doing so usually leads to higher receiver complexity. Therefore, although POLSK has enhanced sensitivity, its practical application can be impeded by the intricacies involved in managing polarization variations. Due to the absence of depolarizing effects in the atmospheric channel, it is very possible to use Polarization Shift Keying (POLSK) modulation in Free-Space Optical (FSOC) systems. During atmospheric transmission, the polarization states undergo minimal interference, enabling their individual detection at the receiver. Although having this advantage, turbulence still causes fading effects that impact the signal in all polarization states. In order to examine the possible advantages of POLSK in this specific situation, we have applied this modulation technique and assessed its effectiveness in a simulated environment with convective turbulence.

Initial empirical findings suggest that POLSK demonstrates superior performance compared to On-Off Keying (OOK), similar to the advantages reported in optical fiber communication systems. Expanding upon previous discoveries, our research broadens the exploration of POLSK-modulated FSOC systems in the presence of obvious air turbulence. We propose a theoretical framework for Free Space Optical (FSOC) systems that employ Phase-Shift Keying (POLSK) modulation. We offer a comprehensive analysis of this methodology. In order to objectively evaluate the system's performance, we created a test environment that included a 1-kilometer FSOC (FSOC) connection between two buildings. This configuration not only facilitates the assessment of POLSK modulation in real-world scenarios but also permits the detection of subtle depolarization effects on a laser beam as it passes through air turbulence. The test-bed is a great tool for evaluating the durability and efficiency of POLSK modulation in real-world FSOC circumstances. POLSK (Polarization-encoded Optical Spatial Keying) transmission encodes information into a constellation of signal points using the Stokes parameters, which are a collection of variables that describe the polarization state of light. The electric field of a plane wave propagating in the z-direction can be described by decomposing it into its parallel and perpendicular components with respect to the plane of incidence. Consequently, the electric field vector of the wave may be divided into two mutually perpendicular components: one that is parallel to the plane of incidence and another that is perpendicular to it. Through the analysis of these elements, the polarization state of the wave may be ascertained, a crucial factor in comprehending the transmission and decoding of information in the POLSK system. This technology utilizes the varying orientations and strengths of the electric field components to efficiently encode and transmit information by altering polarization. This enables a comprehensive and resilient communication system. POLSK (Polarization-encoded Optical Spatial Keying) transmission encodes information into a constellation of signal points using the Stokes parameters, which are a collection of variables that describe the polarization state of light. The electric field of a plane wave propagating in the z-direction can be described by decomposing it into its parallel and perpendicular components with respect to the plane of incidence. Consequently, the electric field vector of the wave may be divided into two mutually perpendicular components: one that is parallel to the plane of incidence and another that is perpendicular to it. Through the analysis of these elements, the polarization state of the wave may be ascertained, a crucial factor in comprehending the transmission and decoding of information in the POLSK system. This technology utilizes the varying orientations and strengths of the electric field components to efficiently encode and transmit information by altering polarization. This enables a comprehensive and resilient communication system.

POLSK (Polarization-encoded Optical Spatial Keying) transmission utilizes receivers that are specifically engineered to extract the three Stokes parameters. These parameters accurately represent the polarization state of the optical signal that is received. In the Differential Dual-Polarization POLSK (DD-POLSK) method, the receiver's first step is to use an optical front-end to convert the incoming optical signal into electrical currents. The magnitudes of these currents are directly related to the linear combinations of the Stokes parameters of the input field. In the subsequent phase of processing, the aforementioned currents are transformed into baseband currents by electronic means. The mean values of these baseband currents correlate to the Stokes parameters of the received field, offering a direct representation of the polarization state. In order to mitigate the problem of unpredictable changes in polarization, which may arise due to channel birefringence, the system includes supplementary polarization tracking processing. Ensuring correct estimation of the transmitted symbols is essential, and this phase plays a critical role in compensating for the effects of birefringence. After compensating for optical birefringence, the detection method uses the computed Stokes parameters to estimate the transmitted symbols. POLSK provides greater versatility in modulation schemes in comparison to the conventional OnOff Keying (OOK). OOK is a binary encoding method, whereas POLSK allows both binary and block encodings. Binary modulation represents the two potential states as the two opposite points on a diameter of the Poincare sphere located in the Stokes space. This binary technique is characterized by its simplicity, as each state occupies a distinct point at the opposite ends of the polarization space. In contrast, M-array modulation entails the assignment of each transmitted symbol to a distinct location in the Stokes space, enabling more intricate encoding. Only the binary POLSK format has been implemented in the Free-Space Optics (FSOC) communication system for the specific objectives of this study. Therefore, this research and the subsequent results are only centred around the binary POLSK modulation scheme, specifically examining its implementation and performance inside the system [69].

Related work: -

1.Freedom from atmospheric turbulence and transmission power, Free-space Optical Communication (FSOC) performance is highly variable. This study proposes a novel communication system called MIMO-CPolSK, which combines the MIMO system with CPolSK modulation. The numerous mathematical models of the atmospheric channel are selected based on the turbulence strength. First, the SISO-CPolSK BER calculation formula is put out. Next, the MIMO-CPolSK and SISO-CPolSK systems' BER performance is showcased. The numerical simulation result demonstrates that BER performance is significantly enhanced in MIMO systems, and when the system has the same BER performance under the same conditions, the SNR of receiving in CPolSK modulation is reduced by roughly 3dB when compared to OOK modulation. First, the Single Input Single Output (SISO) BER formula for OOK and CPolSK modulation is provided. Next, the BER formulas for MISO and MIMO in

OOK and CPolSK modulation are deduced, respectively, as a benchmark. In the essay, the benefits and drawbacks of various modulations and systems are examined using numerical simulation. The optical signal's polarization won't alter. PolSK modulation uses polarization to transmit a signal while utilizing the vectorial characteristics of light. While 2-PolSK uses linearly polarized light to transfer information, CPolSK uses a binary signal. All rights reserved. Without the prior consent of Trans left/right circularly polarized light, no portion of the contents of this article may be duplicated or transmitted in any way. CPolSK modulation does not require polarization axis alignment, in contrast to PolSK modulation. Put another way, if the transmitter and receiver spin at different angles, the system's communication performance remains unchanged. Other than that, CPolSK's scattering light intensity distribution is more homogeneous than PolSK's. After passing through a λ/4 wave-plate and turning to the right or left, the linearly polarized light produced by PolSK modulation transmits through an atmospheric turbulence channel. The receiving light signal flows through a λ/4 wave-plate on the receiver, converting right- and left polarized light into 45˚/-45^ linearly polarized light. Differential reception is then used to detect the receiving signal. When the system approaches the same B, the SNR on the receiver when employing differential reception in CPolSK is reduced by roughly 3 dB in comparison to typical OOK modulation. A new communication system called MIMOCPolSK, which combines MIMO technology for wireless electromagnetic communications with CPolSK modulation for optical communication, was developed to improve the communication performance of the FSOC system. Analyse the BER of the SISO-CPolSK, SIMO-CPolSK, and MIMO-CPolSK systems under varying turbulence strengths by simulating the activity of the atmospheric turbulence channel using various mathematical models. The simulation's result demonstrates that, for any given turbulence channel strength, the BER performance of MIMO systems is significantly higher than that of traditional SISO systems. In addition, under the same conditions, SNR on the receiving is reduced by roughly 3dB in CPolSK systems when BER performance is equal to that of OOK systems [70].

2. Evaluation of BER Performance Using the RoFSOC System with OFDM POLSK over Malaga Distribution High bandwidth and data rate are critical requirements for free space optical communication (FSOC). It is a method of transmitting data wirelessly that disperses light throughout empty spaces like the air, the vacuum, and cosmic space. Its high data rate can reach 2.5Gbps over a few kilometers to a few hundred meters. It uses orthogonal frequency division multiplexing (OFDM), a novel technique termed radio on FSOC, to transport more radio frequency signals. Two modulation techniques—Quadrature Amplitude (QAM) and Polarization Shift Keying (PoLSK)—have been examined in this work. An analysis of the overall performance over the Malaga distribution with several degrees of atmospheric turbulence has been conducted. The Outage probability density function (PDF) and BER provide characteristics of the Malaga turbulence regime. High bandwidth and unlicensed spectrum are two benefits of free space optics, but there are drawbacks as well, including common irradiation, scintillation distributions, interference, and atmospheric turbulence during wireless data transfer. The average bit error rate (ABER) and systems outage probability can be evaluated with the use of mathematical formulae. Improving the accuracy of pointing errors and environmental disruptions is the primary goal [71].

3. Turbulence is a persistent problem in underwater optical wireless communication (UOWC) that is mostly caused by temperature variations in the water. Despite turbulence's crucial impact, the majority of research in the literature has focused on modelling and evaluating the performance of turbulence channels rather than on ways to lessen the consequences of turbulence, especially through experimental work. This study describes the design and experimental testing of a 1 m × 1 m water tank-based UOWC system based on binary polarization shift keying (BPolSK) modulation in a controlled environment. The study looks into how well the system performs with

various transmitted optical power levels and turbulence strengths. The experimental findings show that BPolSK modulation is both feasible and effective in reducing the negative impacts of temperature gradient-induced underwater turbulence. It is demonstrated that the BPolSK system outperforms classical on-off keying (OOK) modulation in terms of bit error rate (BER), especially when an optimal decision threshold is used. This shows that BPolSK modulation has the potential to be a workable approach for enhancing communication reliability in underwater optical links by providing a more robust communication method for UOWC systems operating in stormy conditions. The results highlight the necessity for more research into cutting-edge modulation techniques like BPolSK in order to address the issues raised by underwater turbulence and improve UOWC system performance [72].

4.5 Orbital angular momentum (OAM): -

2004 marked the year that the first experimental demonstration of OAM modulation communication was carried out in free space [73]. This experiment revealed that the utilization of OAM modulation effectively thwarted eavesdropping in a 15-meter free-space optical connection, as depicted. The transmitter comprised a Helium-Neon laser, a Spatial Light Modulator (SLM) containing various phase holograms, and a telescope for beam expansion. Eight phase holograms were created to produce eight distinct orbital angular momentum (OAM) beams. These beams corresponded to certain values of l, namely -16, -12, -8, -4, 4, 8, 12, and 16. Each of these values represented different data information, which could be accessed by switching the phase holograms at different points in time. The receiver utilized a telescope with comparable specifications to decrease the size of the beam, along with an additional Spatial Light Modulator (SLM) and a CCD camera. The phase hologram put onto the spatial light modulator (SLM) was specifically developed to detect the time varying orbital angular momentum (OAM) beams. The hologram was created to disperse the light beam into nine beams, each having a distinct topological charge, organized in a 3 × 3 grid. A Charge-Coupled Device (CCD) was utilized to track and identify the Orbital Angular Momentum (OAM) state. The findings demonstrated that OAM has the potential to encode data onto a laser beam, enabling the transmission of information in free-space optical systems. In 2014, the transmission of OAM superposition modes using modulation was introduced. The high turbulence conditions were seen during a 3-km intra-city link in Vienna [74].

The limited modulation speed significantly hinders the widespread adoption of OAM modulation communication in actual optical communication systems. An investigation was conducted to examine the impact of mode spacing and temporal misalignment between mode channels on switching crosstalk and bit-error rates (BERs). The neighboring modes, which have a mode spacing of one, resulted in an additional power penalty of 3.2 dB as compared to a greater mode spacing. In addition to OAM modulation communications across short distances in laboratory settings, long-distance high-speed OAM modulation communication has also been successfully performed in free space. Two laser beams, each of the same wavelength, are transmitting opposite 25-Gbaud on-off keying (OOK) signals. These signals are being launched into two spatial light modulators (SLMs) that have separate holograms. The two beams were merged using a beam splitter (BS) to convert the temporal domain OOK signals into two orthogonal OAM beams with distinct topological charges. Each Optical Add/Drop Multiplexer (OAM) beam was symbolized. a symbol that fills a time period of 40 nanoseconds. The diagram displayed the configuration of a 260-meter-long data transmission link, operating at a speed of 25 gigabits per second, using OAM modulation. This link connected the WNLO-E building to the WNLO-H building. The diagram was positioned at the bottom and was subjected to the atmospheric conditions. The transmitter and receiver were situated at the WNLO-E building, while the reflection mirror (M) was positioned at the far end of the corridors.

The majority of OAM modulation communications utilize Spatial Light Modulators (SLMs) to generate Orbital Angular Momentum (OAM) beams [74-76]. Despite their excellent performance, these devices are still very large and costly. Photonic integration is a prominent and essential factor in achieving compact, dependable, and cost-effective optical systems that are in high demand for optical communications [77-82]. The light beam that carries orbital angular momentum (OAM), which is a type of structured light beam, is characterized by a helical phase front described by the exponential function exp$il\theta$ where l represents the topological charge and θ represents the azimuthal angle. The topological charge, denoted by the symbol l, represents the twisting rate of the helical phase front. It can take any value and is associated with the handedness of the helix, which is indicated by the sign of l. An OAM beam has a doughnut-shaped intensity profile with a phase singularity at its center due to its helical phase structure. OAM beams have gained significant attention in various fields due to their unique characteristics, such as helical phase structure and doughnut intensity profile. This has led to advancements in astronomy, manipulation, microscopy, imaging, metrology, sensing, nonlinear interactions, quantum science, and optical communications [83].

Photons possess both spin angular momentum (SAM), which is linked to polarization, and orbital angular momentum (OAM), which is connected to the azimuthal phase of the electric field in an optical beam. The OAM, or Orbital Angular Momentum, is a characteristic found in specific laser beams known as vortex beams. These beams have the ability to achieve numerous distinct levels of states. Since the OAM states are mutually orthogonal, they can serve as a basis for multidimensional signal constellations. The capacity to produce and examine states with varying Orbital Angular Momenta (OAMs) through the use of interferometric or holographic techniques [83-87]. Enables the implementation of energy-efficient Free Space Optical (FSOC) communication systems. Regrettably, terrestrial FSOC (FSOC) communication links are adversely affected by atmospheric turbulence, and their quality-of-service (QoS) is contingent upon prevailing weather conditions. When there is atmospheric turbulence, the orthogonality between OAM channels is no longer preserved [89]. The issue of OAM modulation in turbulence was examined by applying the central limit theorem and assuming that OAM crosstalk can be represented using the Gaussian approximation. This assumption holds true when a significant number of OAM modes are utilized. Employing many OAM dimensions in practice leads to receiver complexity that is deemed excessively high. However, the Gaussian assumption is no longer applicable when the number of dimensions is less than ten [90]. By employing orbital angular momentum (OAM) modulation, we can meet the high-bandwidth requirements of future interplanetary communications while maintaining a reasonably low system cost and power consumption. It is therefore possible to use the OAM modulation and multiplexing in conjunction with other degrees of freedom in order to meet the high-bandwidth requirements of future optical communications in deep space and near the earth. Through the utilization of low-density parity-check (LDPC) codes, we are able to achieve a reliable transmission at greater rates, while simultaneously raising the aggregate data rate of the system. This is made possible by increasing the amount of OAM states [91].

Related work: -

1. In this paper, the simultaneous transmission of multiple orbital angular momentum (OAM) based on spatial mode multiplexing (SMM) as an additional effective degree of freedom (EDOF) and quadrature amplitude modulation (QAM) could potentially increase the capacity of a free-space optical (FSOC) communication over radio frequency (RF). In order to potentially increase capacity in wireless communication systems, this study describes the use of hybrid RF/FSOCOAM based on multiple-input multiple-output (MIMO)/SMM employing M-ary modified pulse position modulation (MPPM) and spatial PPM (SPPM). In light of atmospheric turbulence

(AT), we provide an analytical system architecture for MIMO/SMM processing and OAM multiplexing in a free space communications channel. Here, we take for granted a new design that reduces the latency between optical and millimeter-wave (mm-wave) wireless communications. In this investigation, we present current developments in OAM multiplexing applications for mm-wave and high-capacity FSOC communications. We have proposed a novel hybrid SPPM and MPPM version and created the MPPM in FSOC communication via RF utilizing the source Gaussian model and SMM. The unique approach offers improved acquisition, pointing, tracking location, and AT mitigation of the connection performance. In order to reduce the effects of both severe and weak turbulence distortions, we suggest combining SMM with an OAM-QAM based MIMO communications system. According to simulation results, when the propagation distance exceeds a certain threshold, the OAM-based MIMO system's capacity performs better than the traditional MIMO system's capacity. Transmitter lenses could improve the OAM beams by providing a greater mode spacing (MS) of When a bigger lateral movement of approximately 2 mm is overwhelmed by inter-channel crosstalk, 2 (OAM transmitted) exhibits a reduced power penalty (PP). Focusing OAM beams using the transmitter's lenses could lower power loss and power-efficiency in OAM-based FSOC lines. This benefit may be more pronounced for higher-order OAM beams. The system has a mode spacing of 2 (OAM transmitted) and a mode spacing of 3 (OAM received transmitted), with the transmitter and receiver having greater aperture sizes (8 cm and 10 cm, respectively) of OAM beams using MIMO technology should satisfy the lower-power penalty of 2.2 dB and 3.4 dB, respectively. This could improve system resilience to angular error but deteriorate lateral displacement tolerance. For the capacity, the suggested system offers an exceptional signal-to-noise ratio (SNR) in the strong air turbulence domain. This maximizes FSOC communication and wide-band radio frequency (RF) coverage, boosts data capacity, and is seen as a significant answer for future access networks' bandwidth needs. The practical application of OAM-MIMO/SMM multiplexed RF/FSOC lines may benefit from this work [92].

2. The utilization of orbital angular momentum (OAM) beams as data carriers in Free Space Optical Communication (FSOC) systems is the main topic of this work. OAM beams have a lot of potential for mode-division multiplexing, which can greatly increase transmission capacity without relying on particular wavelengths or polarization, because of their intrinsic orthogonality and capacity to carry multiple states. OAM-based FSOC systems are becoming more and more popular for use in secure quantum communications, deep-space, and near-Earth optical communications. A number of fixes have been suggested, including enlarging the beam and receiver aperture and employing specialty beams (such Airy vortex and Laguerre-Gaussian beams) to concentrate more power at the receiver. Although these techniques can improve performance, they can restrict flexibility and complicate system design. Another method of fixing phase distortions is adaptive optics, however this one need more sophisticated equipment. The research also emphasizes Coherent Beam Combining (CBC) as a substitute to preserve beam quality and greatly increase output power. Because CBC enables fast switching between OAM states at GHz frequencies, high-speed optical communication could potentially benefit from its use. By employing CBC, the scientists examined the propagation properties of OAM beams produced by a coherent laser array with discontinuous vortex (CLA-DV). Airborne absorption, scattering, and turbulence cause phase distortions and power attenuation, which negatively affect the performance of OAM-based FSOC systems. Mode crosstalk, in which transmitted OAM modes interfere with neighbouring ones, can be caused by these distortions and deteriorate communication quality. In this sector, reducing mode crosstalk and boosting signal power are the two fundamental problems. contrasting these with beams of Gaussian vortex under comparable circumstances. They provided evidence of CLA-DV's ability to lessen mode crosstalk and enhance OAM-based FSOC systems'

functionality. An optical link based on a radial phase-locked Gaussian laser array is introduced in a suggested communication architecture, and its viability is confirmed by an 8-bit grayscale image transfer. With the results, OAM is positioned as a promising tool for next generation optical communications and offers a theoretical framework for improving OAM-based FSOC systems [93].

4.6. Orthogonal frequency - division multiplexing (OFDM): -

To mitigate the impact of multipath fading caused by atmospheric turbulence, a substantial level of effort is necessary. In OFDM, data is distributed across numerous orthogonal carriers that are effectively segregated at low frequencies, with overlapping bands. This technique has significant potential for reducing the impact of multipath fading produced by air turbulence in FSOC (FSOC). The reason for this is that OFDM provides sufficient separation between the carriers. By employing the fast Fourier transform (FFT), the subcarriers are made orthogonal, so preventing the demodulators from detecting frequencies that do not belong to them. The application of OFDM offers advantages such as increased data capacity, secure transmission, fast speed, and seamless updating [94]. The frequencies that are used by each modulation station in FDM are different. There is a significant amount of frequency difference between each and every frequency signal, which means that they do not overlap with any of the other possibilities that exist inside the frequency spectrum. Each frequency signal is filtered through a band pass filter on an individual basis in order to obtain the opposite complete signal, with the exception of the required signal that the base station is taking into consideration for the receiver. It is necessary to reverse the acknowledged signal in order to get the initial signal [95]. Because OFDM technology allows for the transmission of information over a wide variety of communication carriers, it is becoming increasingly popular.

Carriers frequently experience gaps in their frequency, which ultimately results in a block of spectrum. In accordance with the frequency gap and the temporal synchronization, each and every carrier is produced in an orthogonal fashion. These carriers are produced without encountering any interference within the frequency band in which they are being produced. For the purpose of encoding digital (binary) data on a number of carrier frequencies, digital modulation makes use of a type of digital transmission known as orthogonal frequency-division modulation (OFDM). Wideband digital communication techniques such as orthogonal frequency division multiplexing (OFDM) have gained popularity and are now commonly used in 4G/5G mobile communications, the internet access provided by DSL, wireless networks, power line networks, and the transmission of digital signals for television and audio. The entering bitstream, which is a representation of the data that is going to be sent using OFDM, is divided into further streams. When using OFDM, the effects of multipath fading are mitigated better. OFDM is going to be the source of the high data rate. Using OFDM reduces the amount of interference that occurs during signal broadcasting. Each carrier is modulated with bits from the stream that is coming in, which allows for several bits to be given in at the same time. Because of this, the transmission of a large number of orthogonal subcarrier signals that are closely spaced and have overlapping spectra is produced. The demonstration is built on the foundation of fast Fourier transform methods, and the addition of the guard interval helps to improve orthogonality in transmission channels that are affected by multipath propagation. The modulation of each subcarrier (signal) is accomplished through the utilization of a conventional modulation approach, such as phase-shift keying or quadrature amplitude modulation, when the symbol rate is low. This maintains overall data speeds that are comparable to those of standard single-carrier modulation schemes while continuing to use the same bandwidth. One of the most significant advantages of orthogonal frequency division multiplexing (OFDM) in comparison to single-carrier schemes is its ability to withstand difficult channel conditions. These conditions include frequency-selective fading, narrowband interference, and the attenuation of high frequencies in long copper lines. due to the presence of multipath) without necessitating the deployment of complex equalization filters. Because OFDM can be seen as the utilization of a large number of slowly modulated narrowband signals rather than a single rapidly modulated wideband signal, channel equalization is simplified to a greater extent [96].

By employing orthogonal subcarriers, the FDM system described may have achieved a greater degree of spectral efficiency. The guard bands, which were formerly required to enable separate demodulation of subcarriers in a Frequency Division Multiplexing (FDM) system, would become obsolete. Utilizing orthogonal subcarriers enables the overlapping of subcarriers' spectra, resulting in an enhanced spectral efficiency. As long as the condition of orthogonality is preserved, it remains feasible to retrieve the signals of the individual subcarriers, even if their spectrums overlap. When the dot product of two deterministic signals is zero, these signals are considered orthogonal to each other. Orthogonality can also be understood in terms of stochastic processes. If two random processes are uncorrelated, then they are orthogonal [97].

The OFDM system, being a multi-carrier transmission technique, has the ability to achieve a high data rate while also having the potential to eliminate inter symbol interference that occurs with single-carrier modulation schemes [98].

Related work: -

1. I n this paper we studied about primary goal is to investigate how the free space optical communication (FSOC) system performs in different parts of India while there is rainfall. In order to calculate the specific rain attenuation coefficient, meteorological data on rain intensities for the years 2014–2017 were acquired from the India Meteorological Department (IMD) for potential regions in India, including coastal and inland locales. Additionally, in order to study the system performance for wet weather circumstances in India, we have developed a 16-channel FSOC system based on orthogonal frequency division multiplexing (OFDM), using coherent detection and digital signal processing (DSP). Hyderabad's inland area has an attenuation value of 1.91 dB/km for average rain intensities. It is the very minimum of all the places this work has taken into account. As a result, in the case of Hyderabad, the suggested system design can handle a 5-kilometer FSOC link and give a bit error rate (BER) of about 10−6. Conversely, the Mumbai coastline region experiences the highest average rainfall intensities, and its particular attenuation coefficient reaches its maximum of 4.08 dB/km. As a result, Mumbai's maximum FSOC range is limited to 3.5 km, guaranteeing BER of the order of 10−6. Similarly, under the worst rainfall scenario, the planned FSOC system has also performed better for India's inland regions than for its coastal portions [99].
2. OFDM is a digital technology used in wireless communications and multipath networks for multi-carrier modulation and data delivery. It uses the inverse fast Fourier transform (IFFT), which necessitates the transmission of parallel data streams across orthogonal, frequency-range-matched sub-carriers. Large capacity, tolerance to intersymbol interference (ISI), great spectrum efficiency, and low implementation costs are only a few of the major benefits of OFDM. Numerous investigations on the use of OCDMA codes exclusively, OFDM exclusively, and both OCDMA and OFDM in FSOC lines have been conducted. the OCDMA system in the FSOC link was utilized with a double weight zero cross-correlation (DWZCC) code. When the impacts of air turbulence are taken into account, 25 Gb/s is obtained. The DWZCC algorithm has no cross-correlation, however it is difficult to implement because of its length. The EDW code was allocated to the channels, and the OCDMA/FSOC system's performance was examined in clear, light mist, light fog, and very light fog conditions. Due to the use

of broadband LED, the capacity (3 × 622 Mb/s) was not very high. Since the cross-correlation of this code is unity, the single photodiode detection method was employed to light the MAI. OFDM was used in an FSOC system, and the effects of clear and foggy skies were assessed on the system's performance. The total capacity of their suggested system was 40 Gb/s. The researchers also looked at the effectiveness of their FSOC system using real meteorological data. The effectiveness of the FSOC system suggested by was assessed in the presence of precipitation using meteorological data for Dakar, Senegal's capital, from 2003 to 2013. The suggested technique was able to attain FSOC ranges of 1 to 3.2 km. The FSOC system described in evaluated its performance under clear, fog-filled, and rainy situations. It used OFDM with OCDMA (with EDW codes). 45 Gb/s of transmission capacity was attained by the system [100].

3. The capacity of Free Space Optical Communication (FSOC) to deliver large bandwidth and data speeds has attracted a lot of interest. This method uses light propagation over unconfined media, such air, vacuum, or cosmic space, to enable wireless data transmission. Data speeds up to 2.5 Gbps are supported by FSOC over a range of distances from a few hundred meters to several kilometers. One of its newer uses is radio frequency signal transmission via a revolutionary technique called Radio over FSO, which makes use of orthogonal frequency division multiplexing (OFDM). In this paper, we investigate the functionality of FSOC systems with two different modulation methods: Polarization Shift Keying (PoLSK) and Quadrature Amplitude Modulation (QAM). The analysis focuses on the impact of Malaga distribution to model the effects of air turbulence, ranging from weak to strong situations. Key performance indicators such as Bit Error Rate (BER) and Outage Probability are investigated through the Probability Density Function (PDF) under varied turbulence regimes. Even while FSOC has several benefits, such as the ability to utilize unlicensed spectrum and access high bandwidth, it also has drawbacks, including atmospheric turbulence, interference, and radiation scintillation. Data transmission may be greatly impacted by these variables. Additionally, the study offers mathematical models for calculating the Average Bit Error Rate (ABER) and Outage Probability of the system, which are essential for determining how well the system performs in the face of pointing errors and environmental disruptions [101].

4.7 Colour shift keying (CSK): -

VISIBLE light communication (VLC) systems are able to transmit information via a wireless environment because they rely on visible radiations. High data rates and unrestricted visible spectrum are also features offered by VLC [102-104]. In recent years, there has been a growing interest in visible light communication (VLC) due to its unique benefits, including a wide range of available frequencies, energy efficiency, absence of radiation, and other advantages [105]. VLC systems employ a technology called intensity modulation and direct detection (IM/DD). White light emitting diodes (LEDs) are commonly employed as the source in visible light communication (VLC) applications. Photodetectors are employed at the receiver to detect the signal transmitted through the wireless channel. Moreover, the utilization of VLC in combination with RF transmission holds the potential to address the current challenges faced by wireless communication [106]. There is a very rapid increase in the amount of data traffic that is being transmitted over mobile, wired, and Wi-Fi networks. On the other hand, the advances in spectrum efficiency for radio frequency networks are reaching their maximum level. As a result, it appears that there is a possibility that there will be a substantial shortage of network capacity in the very near future. One alternative is to make use of visible content that is not licensed. The spectrum that is available for wireless communication within buildings. The RF network will not only benefit from this, but it will also provide spectrum relief. However, it will also make mobile communication easier and more convenient. less prone to interference and more efficient in terms of energy use [107]. Wireless Visible Light Communication (VLC) can achieve high data speeds in indoor environments thanks to its high signal to noise ratio (SNR), typically equal to or more than 60 dB [108]. Because it makes use of three different coloured LEDs (also known as trichromatic LEDs) as a source, the CSK PHY system is also known as the TriLED (TLED) system. All of the problems that were taking place within the TLED CSK system with regard to the detection process and symbol mapping have been resolved. A highly innovative four-color LEDs-based CSK modulation system, which is referred to as the Quad LED (QLED) system, is described. This system is able to solve the problems that are present within the TLED scheme and offers improved performance by making efficient use of the available chromatic (or colour) and intensity (or signal) spaces [109]. Drost et al. [110] and Monteiro et al. [111] I have proposed many constellations designs to enhance colour balancing for the current TLED CSK. Butala et al. have advocated the use of more than three LEDs in CSK to enhance the colour rendering effect. They suggest employing numerous TLED sets, each capable of producing its own gamut. However, Butala et al. propose that their approach will necessitate the receiver's ability to differentiate between the active TLED sets at the transmitter, potentially augmenting the intricacy of the system. However, our motivation for developing the QLED CSK system stems from the communication limitations of the TLED CSK system. This study provides a comprehensive description of the system model of QLED CSK, which utilizes maximum likelihood (ML) detection with multilayer constellations and symbol mapping. The QLED system employs multiple sets of TLED systems, identical to the one described in the previous explanation. Nevertheless, the arrangement of constellations in QLED guarantees that any modulation will only produce the portion of their colour range that is not shared with any other set of TLEDs. An important achievement of this study is the creation of a four-dimensional (4-D) constellation for the QLED system by merging four sets of three-dimensional (3-D) constellations. This enables the recipient to consider the immediate intensities detected as a single point in the four-dimensional signal space. As a result, the recipient does not have to distinguish between the active sets of TLEDs at the transmitter [112].

The intensity of the visible light that is emitted by multicolor LEDs is modulated by CSK in order to facilitate the transmission of information. The x-y colour coordinates, which were determined by the International Commission on Illumination in the CIE 1931 colour space, serve as the foundation for the modulation system [113]. The CIE 1931 colour space chromaticity diagram displays the complete range of colours that may be perceived by the human eye, together with their corresponding chromaticity values x and y. The vibrant area depicts the whole range or spectrum of human visual perception. The curved boundary with nano meter-specific wavelengths is known as the monochromatic or spectral locus, while the straight boundary [114]. In order to generate a CSK signal, it is necessary to utilize three distinct light sources in the system [115]. For example, monochromatic colour LEDs like Blue, Green, and Red have specific center wavelengths. The LED sources emit a combination of light that enables CSK to reproduce different colours found in the constellation triangle and use these colours as data signals [116-117].

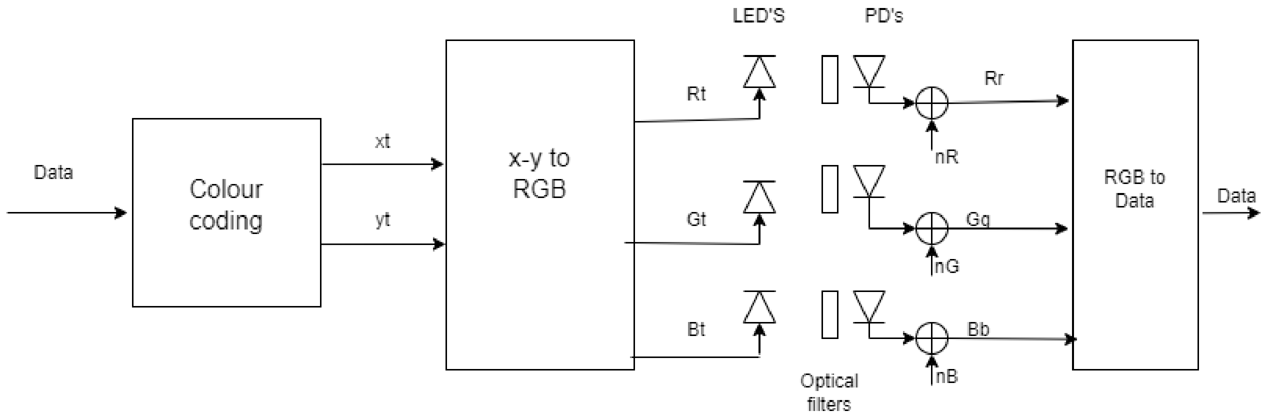

Fig. 4. Uncoded TLED CSK system [112].

The figure 2 displays the block diagram of the uncoded TLED CSK system. In this design, xt, yt, and Rt, Gt, Bt indicate the chromaticities and intensities at the transmitter, respectively. Rr, Gr, and Br represent the intensities at the receiver. The noise for each detector, which is independent and identically distributed, is denoted as nR, nG, and nB, representing the additive white Gaussian noise. The TLED system initially maps binary data onto x and y chromaticities. These chromaticities are then transformed into intensities Pi, Pj, and Pk (or R, G, and B) using the following set of equations [112].

When a different color LED is used, the center wavelength chromaticity is the only thing that changes. At the receiving end, the narrowband optical filters allow light of the wavelength to pass through. PDs with the range you want. The PDs pick up the intensities of light that hits them, and the binary data is taken from each set of intensities (Rr, Gr, and Br) [117]. Alternatively, to enhance performance, CSK can be integrated with other modulation techniques, such as pulse position modulation (PPM) [116]. In addition, optical orthogonal frequency division multiplexing (OOFDM) has been implemented in visible light communication (VLC) systems to enable high-speed data transfer, taking into account the potential effects of inter-symbol-interference (ISI) [118]. There is no text provided. Therefore, the integration of CSK with OOFDM has been suggested to improve the transmission efficiency of VLC systems [119]. Nevertheless, this uncomplicated fusion presents two significant problems. The CSK-OOFDM system utilizes the Hermitian symmetry operation, resulting in real-valued signals following the inverse fast Fourier transform (IFFT). In this scenario, the CSK constellation consisting of real values used before the OOFDM modulator does not take advantage of the available complexity in the complex domain. In order to address this problem, we developed a PM-CCSK-OFDM system [120] that combines two pre-existing real-valued CSK constellations. However, it should be noted that this approach does not ensure the optimal construction of the constellation. Furthermore, due to the spreading of the input frequency-domain CSK signal across the time domain during the IFFT operation, the resulting colour of the OOFDM-modulated VLC signal is likely to differ from the original CSK constellation, which is commonly white. Distorting the colour balance in this way violates typical illumination requirements, which is a problem that existing approaches rarely address [121]. It appears that LED based lighting solutions will eventually completely replace conventional lighting. The world's requirements are always being met by technology, and since the entire economy is turning toward sustainability and ecology, switching to low consumption LEDs would seem like a sensible course of action. The quick on/off switching of LEDs opens the door to the potential development of new optical communication systems. Photodetectors serve as the receiver in (VLC) systems, while LEDs act as the transmitter. Image sensors are used as the receiver in Optical Camera Communications (OCC), a technology that is comparable to VLC. The study explores the performances of several fsoc technologies and provides a full overview of the areas and applications in which they can be found [122].

Related work: -

1. With the increasing issues that microwave bands face, including poor interior propagation characteristics and larger route losses, Line of Sight (LOS) optical communication has become a viable solution. As a result, Light Fidelity (LiFi) was conceptualized. This technology uses light as a communication medium and is especially useful indoors, where most mobile traffic happens. For effective energy use and communication, LiFi can be integrated into common lighting systems that employ LEDs or laser sources. It provides high data transmission capacity while removing RF pollution. However, with higher data rates, traditional modulation systems like PPM (Pulse Position Modulation), PAM (Pulse Amplitude Modulation), and OOK (On-Off Keying) encounter propagation problems. Time division multiplexing makes these techniques less effective in optical wireless channels, which causes problems with frequency selectivity. By dynamically allocating subcarriers, OFDM (Orthogonal Frequency Division Multiplexing) provides a flexible substitute that allows users who are geographically separated to have different data rates. A important innovation in tackling multiuser access difficulties in the LiFi uplink is Color Shift Keying (CSK), a modulation technique specified in IEEE 802.15.7. Using RGB LEDs' varying color output to enhance signal modulation, CSK encrypts signals into color intensities. This method provides improved control over color quality in communication systems along with energy savings. Using CSK as a foundation, metameric modulation (MM) improves spectral efficiency even more. DCO-OFDM (Direct Current Orthogonal Frequency Division Multiplexing) is a cost-effective and simple-to-use technique for LiFi networks. In this method, geographically dispersed users' intensity-modulated subcarriers are merged to generate an optical signal at the router. Because the composite signal may be obtained using basic optical detectors and FFT hardware, this method enables cost savings. An option is offered by non-DC biased OFDM (NDC-OFDM), in which various optical units transmit the positive and negative components of the OFDM signal independently. In the end, OFDM reduces system complexity by using optical carrier envelope modulation and cheap red lasers to offer an effective multiuser access solution in LiFi networks. To further optimize cost and performance in LiFi communication systems, this approach can be expanded to gather subcarriers from several access points, combine them via passive optical fibers, and transmit them to a remote OFDM router [123].

2. For VLC systems that use photodetectors like PDs, common modulation techniques include variable pulse position modulation (VPPM), color shift keying, and on-off keying (OOK). Accordingly, new modulation schemes pertaining to the use of digital cameras' IS, such as rolling shutter frequency shift keying (RS-FSK) and camera on-off keying (COOK), were included to the updated version of the standard modulation schemes. The reduction of flickering in the formatted optical signal utilizing coding algorithms, such as run-length limiting (RLL) and Reed-Solomon (RS) encoders, with simultaneous clock recovery and error detection capability, is another significant challenge that emerges in VLC. Despite the fact that the aforementioned encoding schemes are well defined by the standard, a lot of research has been done on alternate methods of error detection and correction. For example, polar code (PC) rather than RS is used in CSK modulation VLC systems, and there are two types of LDPC codes. These days, the transmitter's power supply, LED characteristics, and LED driving sub-circuit are the key subjects of research. Still, given the receiver of a VLC system, the research effort is insufficient. In the meantime, the receiver's AFE is a crucial component of a VLC system. After receiving the visual signal, it transforms it into an electrical signal that is amplified, filtered, and processed in order to become digital. The few studies that have been done in the literature have mostly concentrated on the fundamentals of receiver

construction, such as how to amplify a received signal using a trans-impedance amplifier (TIA). As a result, studies on the AFE of the receiver are crucial since they help a VLC system run smoothly.so for the Effective Current Pre-Amplifiers for Visible Light Communication (VLC) Receivers we used the csk modulation which gives us more benefits other than any modulation technique [124].

4.8. Quadrature amplitude modulation (QAM): -

This research investigates a unique method of combining orbital-angular-momentum (OAM) multiplexing with hybrid polarization-division-multiplexing (PDM) to improve data transmission in free-space optical communication (FSOC) systems. The suggested system offers a very effective communication architecture by multiplexing six user signals using a single-wavelength spatial laser. Using non-return-to-zero (NRZ) encoding and 4-QAM modulation over a 60 GHz radio frequency (RF) carrier, the system simulation uses a Gamma-Gamma fading channel to achieve a data rate of 2 × 3 × 10 Gbps. Three Laguerre-Gaussian (LG) modes (LG01, LG02, and LG11) are linked to each of the two polarization states that are implemented: X-polarization (X-PL) and Y-polarization (Y-PL). With 10 Gbps of data carried by each LG mode, a total of 60 Gbps of transmission bandwidth is possible. By modeling the FSOC link in Baghdad, Iraq, under various weather conditions and transmission distances, the system's performance is assessed. Propagation length, beam divergence, eye-diagram analysis, and bit error rate (BER) computations are used in the study as important performance parameters. The system shows that it can transmit 60 Gbps in clear-air, in the rain, and in light dust over FSOC lines with BER values of 10^{-5}, 10^{-7}, and 10^{-6}, respectively. The greatest transmission distances that can be achieved are 300 meters in light dust, 600 meters in rains, and 800 meters in pure air. These findings show that, even in difficult atmospheric circumstances, the hybrid PDM-OAM system has a great deal of potential to improve data capacity and transmission reliability in FSOC systems. By proving that it is possible to combine polarization and OAM multiplexing techniques to increase data throughput while retaining reliable performance under a range of environmental conditions, the findings aid in the development of advanced FSOC systems. This study emphasizes how crucial it is to take weather into account while developing FSOC systems for practical uses, especially in areas where atmospheric disturbances are common [125].

The synchronization parameters' CRLB varies based on the SNR region. In actuality, for QAM signals, the CRLBs for the joint phase and frequency estimates were empirically assessed at moderate and high SNRs using Monte Carlo evaluation, and numerically estimated at low SNR values from extremely complicated expressions [126]. However, for PSK signals, approximate analytical formulas for the carrier phase and frequency exact CRLBs were derived in utilizing a Taylor series expansion of the log-likelihood function [127]. the specific instances of QPSK and BPSK/MSK communications. However, there are no closed-form formulations for the precise CRLBs of the carrier phase and frequency offset NDA estimates when taking into account higher-order QAM constellations, which are and will be widely employed in present and future high-speed communication technologies. The derivation of the analytical expressions for the NDA CRLBs of the considered synchronization parameters from any square QAM waveform over AWGN channels, further assuming that the noise power and the signal amplitude are both completely unknown [128][129]. Antenna polarization can be utilized to realize 16QAM spectral efficiency with four-level ASK modulation [130]. The rectangular 8QAM signal performs better than the other 8QAM signal types at lower coding rates [131]. The inverse format conversion from the rectangular 8QAM signal to the QPSK and BPSK signals is absent from both of these methods. The converted QPSK still has two amplitude states, and the aggregated rectangular 8QAM signal is not formed, despite Xiaoxue Gong et al.'s proposal of an AOFC technique based on phase-sensitive amplification (PSA) that converts one rectangle

8QAM to one QPSK and one BPSK [132]. Based on nonlinearities and an optical frequency comb, Alan E. Willner et al. have reported an all-optical format conversion system from three BPSK signals to one rectangular 8QAM signal [133]. It is more advantageous for the optical node to have a bidirectional format conversion function between complex and basic modulation formats, such as the ability to aggregate and de-aggregate signals of QPSK, BPSK, and rectangular 8QAM. A single destination can be used to combine low-speed data flows modulated by simple modulation formats with high-speed data flows modulated by advanced modulation formats. In general, the SE of complex modulation formats is higher than that of simple modulation formats. Consequently, in the multi-point-to-point (MP2P) scenario, the aggregation of the BPSK and QPSK signals to the rectangular 8QAM signal may be appropriate [134]. The transition coefficient (TC) between quadrature phase shift keying (QPSK) and 16-ary quadrature amplitude modulation (16QAM) signals can be fully filled by 8-ary quadrature amplitude modulation (8QAM) signals. It can generally handle more than 50% more data than a QPSK transmission and can withstand more noise than a 16QAM signal. Numerous researchers have studied and experimented with different kinds of 8QAM signals in optical transmission systems [135][136][137][138][139][140].M-QAM and other higher order modulation formats have garnered attention in recent years because to their ability to boost a single-wavelength channel's spectral efficiency [141]. In addition, the rectangular 8QAM signal has been extensively studied in various scenarios such as underwater video light communication, bit-interleaved coded modulation (BICM) channel, flexible orthogonal frequency division multiple access-passive optical network (OFDMA-PON), asymmetric constellation transmission in coherent FSOC with spatial diversity, and asymmetric pair mapping over a seven-core fiber. The star-8QAM signal can also be gray coded and may be more widely used in practical transmissions [142],[143],[144],[145],[146]. To attain a higher capacity, spectrally efficient QAM with discrete multitone (DMT), orthogonal frequency division multiplexing (OFDM), or carrier less amplitude and phased (CAP) modulation has been used in UWOC. A suggested and experimentally verified UWOC system uses a low-cost 150-MHz positive-intrinsic-negative detector and a straightforward, economical TO56 transverse multimode green-light laser diode (LD) [147].

Related work: -

1. Because of its distinct benefits, the mid-infrared (mid-IR) band is becoming a viable choice for wireless communication in the future. Because of its low propagation loss, signals can move through the air more effectively and with less loss of energy. Furthermore, mid-IR frequencies are dependable for communication outside due to their strong resistance to atmospheric disturbances like fog and rain. The quantum cascade laser (QCL) is a crucial technological advancement that makes mid-IR communication possible. QCLs are perfect for small, effective communication systems because they can be integrated into smaller devices and modulated at high speeds, enabling quick data transmission. Therefore, there is a lot of promise for creating cutting-edge wireless communication networks in the mid-IR band and QCLs. In this advance technology we used two types of modulations Specifically, discrete multitone (DMT) modulation and four-level pulse amplitude modulation (PAM-4) are shown. Discrete Multitone Modulation (DMT) is an extremely effective technique for high-speed optical communication that allows data to be transmitted simultaneously over many frequencies. In contrast to single-carrier systems, which transfer data over a single frequency, DMT splits the input data into multiple streams and sends them across numerous subcarriers (SCs) at various frequencies. Data can be encoded into different frequency bands by a mathematical technique known as the Inverse Fast Fourier Transform (IFFT), which is used to divide the data. Pilot symbols aid in estimating the status of the channel to increase decoding accuracy, and a cyclic prefix (CP) is added to prevent errors caused by overlapping data, often known as intersymbol interference

(ISI). DMT in comparison to the fourlevel Pulse Amplitude Modulation (PAM-4) modulation technology. Although PAM-4 is easier to set up and performs similarly to conventional binary systems, it needs a lot of pre- and post-equalization to keep the signal intelligible, especially in systems with constrained bandwidth. DMT is more flexible for systems where the frequency response of the channel fluctuates and is naturally better suited for frequency domain equalization, even if it requires additional hardware to perform its more complicated processing steps like FFT and IFFT. Several modulation forms, including 16QAM, 64QAM, and 128QAM, were examined in tests using DMT. Depending on the Signal-to-Noise Ratio (SNR) of the subcarriers, each modulation scheme offered a varied amount of data transmission efficiency. In order to further optimize the data rate, a fourth bit-loading method was also assessed. In this scheme, various subcarriers were given varied modulation orders according to their SNR. These strategies all achieved the Bit Error Rate (BER) needed for "error-free" transmission. The experiment shows that although DMT requires additional hardware and can experience power spikes due to its high PAPR, it offers higher flexibility and performance in complicated systems compared to PAM-4, which may be easier to deploy. Each modulation method has advantages and disadvantages, and how each is used in a communication system will rely on those factors [148].

2.This is Analysis of Scintillation Effects on Free Space Optical Communication Links in South Africa in order to investigate how air turbulence affects optical signal transmission, one experiment called the First European South African Transmission Experiment (FESTER) was carried out in South Africa. The study discovered that wind direction and speed have a significant influence on optical turbulence; onshore winds during the winter exhibit the lowest levels of turbulence, while summer circumstances exhibit the highest. The refractive index structural parameter (C2n), which is dependent on wind speed and altitude, is a measure of the turbulence's strength. It is easier to develop FSOC systems that can function more dependably even under tumultuous circumstances when these environmental elements are understood. In conclusion, FSOC has a lot of promise to enhance 5G backhaul networks, but its effectiveness is mostly reliant on atmospheric conditions. QAM and other advanced modulation methods provide ways to reduce atmospheric obstacles and enhance data transfer. Optimizing these systems to deal with the unpredictability of weather and environmental circumstances is still a challenge, though. In this paper they explain how various modulation formats are applied. Higher data capacities and improved transmission efficiency are made possible by advanced formats like MQAM and MPSK. OOK and BPSK are examples of simpler formats that are simpler to generate and receive. Optimizing network performance involves converting between various formats, which presents a hurdle. the benefits of employing a certain kind of modulation format known as rectangular 8QAM. It achieves equilibrium between noise tolerance and data capacity. Numerous scholars have looked into how to translate various signals into this format and the other way around. Converting rectangular 8QAM back into more basic formats, such as BPSK and QPSK, which are required for devices with simpler receivers, has, nevertheless, received little attention [149].

3. Because the various OAM modes are mutually orthogonal, OAM has drawn interest as a potential method for improving spectrum efficiency and channel capacity. However, in free-space optical communication, the spiral phase front of OAM modes is very vulnerable to air turbulence (AT). The spiral phase may be distorted by this turbulence, leading to random noise and signal variations that deteriorate signal integrity and cause symbol errors, which lower system performance. This work suggests a frequency-domain equalization technique intended to reduce the signal tremor brought on by AT in order to address these problems. The least squares (LS) algorithm is used to create an optimum estimation response matrix, which forms the basis of the methodology. Reducing the detrimental impacts of air turbulence and enhancing overall system reliability are the objectives. The

suggested method's viability and efficacy were confirmed through both theoretical analysis and experimental application. The findings demonstrate that using the optimized response matrix can greatly lessen the signal wobble brought on by AT. The bit error rate (BER) and constellation plot (CP) for quadrature amplitude modulation (QAM) signals show that this improves system performance. The results verify that the suggested equalization method successfully reduces the negative impacts of air turbulence on optical multimode (OAM) communication systems, resulting in improved signal stability and reduced bit error rate. This work demonstrates how sophisticated signal processing techniques can be used to overcome atmospheric interference problems in free-space optical AM systems, increasing their viability for high-density, high-efficiency optical communication networks [150].

4. from this paper we get the info about Data from the tag's memory or sensors is often communicated to a remote reader via Amplitude Shift Keying (ASK) or Phase Shift Keying (PSK) backscatter modulation in traditional passive UHF RFID tags. One bit of data is transmitted each symbol period using these modulation techniques. An on-chip oscillator with a frequency at least equivalent to the data bit rate is necessary for this method to be executed on an integrated CMOS tag integrated circuit. However, in order to account for backscatter phase rotation that happens when the tag moves in relation to the reader, most contemporary UHF RFID readers use In-phase/Quadrature (I/Q) demodulation. A proposed technology for backscattering is Quadrature Amplitude Modulation (QAM) to take advantage of the current infrastructure and minimize power consumption. This technique eliminates the need for on-chip inductors and is intended to work with a single-chip CMOS tag implementation. The capacity to send multiple bits per symbol period is the main benefit of QAM backscatter. This enables designers to send data at a faster rate without raising the oscillator frequency, or to employ a lower-power on-chip oscillator running at the lower symbol rate while retaining the same data throughput as ASK or PSK. Considerable advantages are provided by this method in terms of data rate optimization and power efficiency. In addition to providing simulated Bit Error Rate (BER) and Error Vector Magnitude (EVM) performance curves for inductor-free 4-QAM and 8-QAM modulators, the study discusses the basic design formulae required for arbitrary QAM backscatter modulators. These modulators are tested in the global UHF band between 860 MHz and 950 MHz operating at 915 MHz [151].

5. CONCLUSION

This study looked into a number of modulation methods, including BPSK, OAM, OFDM, PoLSK, CSK, PPM, and QAM, that are used in FSOC systems. These modulations each have their own benefits and drawbacks, according to an examination done on each approach, including the underlying theory and associated work done on each. BPSK is an error-resistant modulation technique that is simple, reliable, and strong, making it a solid choice for basic FSOC systems. Its employment in high-bandwidth applications may be hampered by its data rate restrictions, though. PoLSK improves capacity and data rate by utilizing the polarization dimension to increase data throughput. Its vulnerability to polarization alignment problems adds even more complication in spite of its benefits. While there are implementation and optimization issues, CSK effectively increases data transmission capacity by utilizing wavelength fluctuations, providing resilience against changing atmospheric conditions. PPM is distinguished by its exceptional data integrity maintenance capabilities and resilience to noise. It works effectively in noisy conditions because of its ability to encode data based on pulse timing. Its comparatively modest data flow in contrast to other methods, though, might be a constraint. On the other hand, because QAM can send more than one bit per symbol, it can transfer more data at a higher efficiency in FSOC systems. QAM maximizes bandwidth use by modulating both amplitude and phase, which makes it very useful in high-capacity and high-bandwidth FSOC applications. In contrast to more straightforward modulation methods like BPSK or PPM, QAM is more susceptible to noise, interference, and atmospheric turbulence, and its performance is strongly reliant on the quality of the communication channel. In summary, the study highlights that when applied to FSOC systems, every modulation approach has certain advantages and disadvantages. OAM and CSK greatly increase capacity, while BPSK and PPM offer resilience and resistance to noise. OFDM increases the efficiency of data transmission, while PoLSK uses polarization to increase throughput. Among the most effective methods for FSOC communication, QAM stands out for its exceptional data rate and economical bandwidth utilization, particularly in high-data-rate situations. Its sensitivity to outside factors like phase noise and turbulence, however, needs to be properly controlled. Specific system requirements, such as data rate, environmental factors, and system complexity, should direct the selection of an appropriate modulation approach. It is advised that more study be done to investigate hybrid modulation methods and technology developments in order to enhance FSOC performance and handle the difficulties involved in each approach, particularly when it comes to optimizing QAM for changing atmospheric circumstances.

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